# Design Criteria for Indoor Positioning Systems in Hospitals using Technological, Organizational and Individual Perspectives

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Für Isabell Altmüller, Antje und Michael Wichmann und die Familie

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# List of Abbreviations

| | |
|---|---|
| A | Appendix |
| AISeL | Association for Information Systems Electronic Library |
| AoA | Angle of Arrival |
| BLE | Bluetooth Low Energy |
| CR | Critical Realism |
| IEEE | Institute of Electrical and Electronics Engineers |
| IPS | Indoor Positioning System |
| IR | Infrared |
| IS | Information System |
| IT | Information Technology |
| kNN | k Nearest Neighbor |
| PDR | Pedestrian Dead Reckoning |
| PICOS | Participants-Intervention-Comparators-Outcome-Study (design) (approach) |
| PPDF | Project Performance Development Framework |
| PRISMA | Preferred Reporting Items for Systematic Reviews and Meta-Analyses |
| RAA | Reasoned Action Approach |
| RF | Radio Frequency |
| RFID | Radio Frequency Identification |
| RSSI | Received Signal Strength Indicator |
| SEM | Structural Equation Modeling |
| SRMR | Standardized Root Mean Square Residual |
| ToA | Time of Arrival |
| TOE | Technology-Organization-Environment (framework) |
| UWB | Ultrawideband |
| Wi-Fi | Wireless Fidelity |

# 1 Synopsis

## 1.1 Introduction

In the recent past, digitalization and resulting measures have made organizations strive to simplify their services to increase customer satisfaction [53]. Those digitalization measures are presented in the Gartner Hype Cycle, which provides an estimate of how many years the corresponding digitization measure will take to reach the Plateau of Productivity. This plateau represents the widespread adoption and use of digitization innovation [17]. In 2019, Gartner noted that Indoor Positioning Systems (IPS) are "climbing the slope," meaning that IPS are expected to become widespread soon [17], with Gartner specifically referring to the next two years for IPS [16]. Recent market studies from 2021 [34] and 2022 [1] found that companies across a wide range of industries are currently investigating how best to implement IPS. For the optimal implementation of IPS, it is important to examine it in its respective environment, as its performance is dependent on the application scenario [8, 40]. One important application scenario to test IPS is hospitals [2, 8, 31, 40, 53], as the performance of the IPS is contingent on radiations in its environment [53]. In hospitals, such radiations exist, at least in certain departments, such as x-ray [40]. Hospitals are characterized as organizations whose buildings are frequently accessed by temporary visitors (patients and their related visitors). Those temporary visitors are forced to enter the buildings due to the treatments they expect to receive or the individual they are going to visit. COVID-19 again highlighted that, in addition to hospital efficiency in treatment, appropriate hygiene is of particular importance to prevent the spread of diseases. IPS support measures to prevent the spread of diseases, such as social distancing [12, 48, 49]. Thus, extensive research on the technology adoption of IPS in hospitals is necessary [31, 44, 53], eg, concerning users' intention to use such a system [48].

An IPS is dedicated to determine a specific position in a building to serve several functions, such as navigating individuals through the building and finding objects in it [31, 53]. To estimate the specific position, technologies for IPS are necessary (such as Wireless-Fidelity (Wi-Fi) or Bluetooth Low Energy (BLE)) that use certain IPS techniques (such as Angle of Arrival (AoA) or Time of Arrival (ToA) [31, 53]). Those techniques are, on occasion, improved by prediction improving methods (such as k Nearest Neighbor (kNN)) to improve IPS performance due to data-grouping [32, 51]). As healthcare and hospitals are important application areas for IPS [26, 31, 44, 53], research on IPS adoption in hospitals is necessary. As an example, Figure 1 depicts an exemplary setup for IPS in hospitals, showing that the position of tags (eg, attached to a wheelchair), mobile devices, and wristbands can be determined by IPS using routers. To date, several IPS approaches exist that consider certain enhancements for in-hospital use, such as managing treatments within the hospital [41] and specific IPS functions for visually impaired individuals [53].

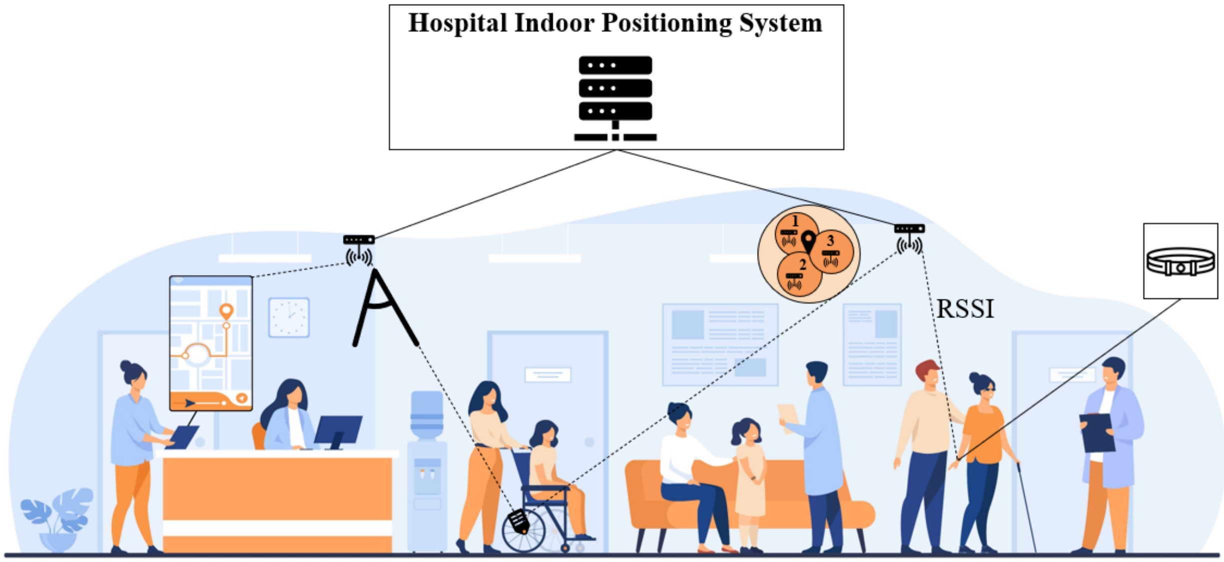


*Figure 1: Functional setup of an exemplary positioning system in a hospital according to Wichmann and Leyer [48]*

For preparing technology (and IPS) adoption, several methods are appropriate that address different perspectives and determine requirements for adoption. By considering the individual perspective, methods that try to predict behavior are sufficient for technology adoption research. Such methods are Reasoned Action Approach (RAA) [13] or Unified Theory of Acceptance and Use of Technology (UTAUT) 2 [45]. Regarding the organizational perspective, widespread methods for investigating technology adoption are fit-viability theory [28, 29, 39, 43] and Technology-Organization-Environment (TOE) framework [10, 14, 15]. While the fit-viability theory takes a holistic approach into account, investigating several IS companies are confronted with [28, 29, 39], TOE framework is more generic [5]. Thus, TOE can be adopted to a specific IS in a specific application scenario [4, 5, 10], such as IPS for hospitals. Hence, this dissertation is guided by TOE that requires the determination of propositions concerning technological, organizational, and environmental contexts [10]. Further, organizational and individual perspectives are considered, as recent extensions of TOE framework suggested [4]. To investigate organizational and individual perspectives, mixed methods (that are quantitative and qualitative) are appropriate [4]. On behalf of the perspective of individuals, RAA is more sufficient for application scenarios where the IS in question (eg, IPS) has not been implemented yet, since UTAUT2 requires the determination of the individuals' actual behavior [13, 45], eg, after using IPS in hospitals. Further, recent extensions of TOE [4] specifically suggest using RAA or UTAUT2 to investigate the individuals' opinions quantitatively. Regarding the organizational perspectives, various methods are sufficient for TOE that can be measured quantitatively, such as experiments or questionnaires, or qualitatively, such as interviews with experts [5, 27]. Simultaneously, the measures for both, individual and organizational perspectives, are relevant for developing design criteria for IPS, as design science in information systems research suggests [20]. While individual perspectives in this dissertation mainly contribute to the problem relevance of IPS in hospitals, organizational perspectives propose criteria for design evaluation [20]. Thus, to investigate individual and organizational perspectives and to determine relevant design criteria, this dissertation aims to answer the following research questions:

*Should IPS be implemented in hospitals? If so, what are relevant design criteria for IPS in hospitals using technological, organizational, and individual perspectives?*

To answer the research questions, the relevant perspectives are embedded in the TOE framework. This embedding is shown in Figure 2.

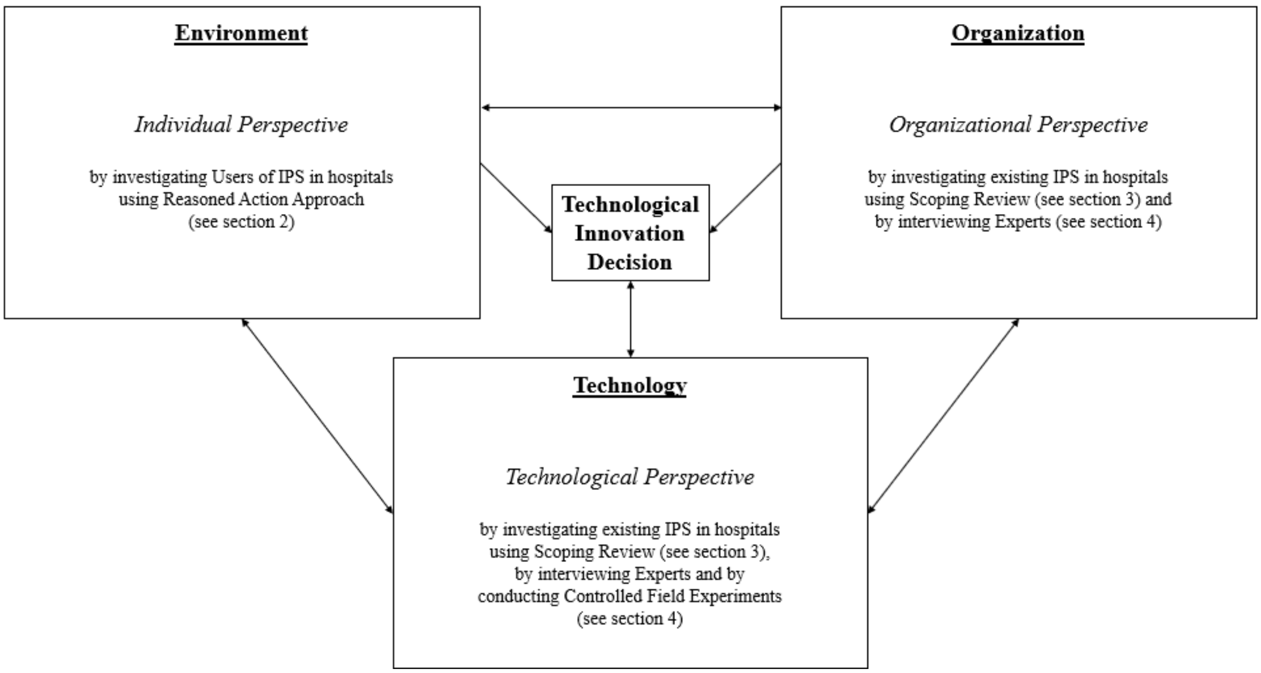


*Figure 2: TOE framework according to DePietro et al. [10] to address perspectives of the dissertation*

From an organizational point of view, the temporary visitors are external parties that visit hospitals less frequently than the respective hospital staff. Thus, as IPS are supposed to be used by external and internal users [48], the users are assigned to the environmental context of TOE. Ultimately, the users determine whether or not to support the technology in question (eg, represented by the intention to use by applying RAA [13]). This technology support is important for the environmental context of TOE [5, 10]. The SR contributes to both, the technological and environmental context of TOE. Concerning the organizational context, the SR provides a review of application scenarios of IPS in hospitals that was used for preparing expert interviews. Those application scenarios are important to understand the integration of IPS in hospitals and the functions they provide (referred to as linking structures in TOE) [5, 10]. Regarding the technological context of TOE, the SR summarizes performances of IPS in hospitals, as well as the technology, technique, and prediction-improving method used by the respective IPS. The summary is important to understand the characteristics of IPS in hospitals, as stated by TOE [5, 10]. We used these findings to design and conduct CFEs by investigating an ultrasound-based IPS for hospitals. The CFEs contribute to the characteristics of IPS in hospitals that are important for the technological context of TOE [5, 10]. Additionally, expert interviews were conducted that addressed both, the technological context as IPS performance criteria were addressed as well as IPS functions regarding the organizational context. IPS performance criteria are important measures for the characteristics of IPS in hospitals that contribute to the organizational context of TOE [5, 10]. The IPS functions help to understand internal and external linking structures and the integration of IPS in hospitals better, which is important for the organizational context, according to TOE [5, 10].

This dissertation is organized as follows: Section 1.2 presents the research philosophy used while section 1.3 describes mixed methods in technology adoption research in healthcare. The concept of the dissertation is shown in section 1.4 and the results of the dissertation are described in section 1.5. The results are then discussed in section 1.6 and implications were derived that are presented in section 1.7. Ultimately, section 1.8 provides limitations of the dissertation as well as directions for future research.

## 1.2 Research Philosophy

The critical realism theory (CR) according to Bhaskar [7] is used as the research philosophy for this dissertation. CR as a philosophy assumes that independent of individual perceptions, a real-world exists whose mechanisms influence research findings within the context of CR [7]. Then, actual events exist that were generated by those mechanisms. Those actual events can be investigated empirically by observable experiences [7]. The relationship between real mechanisms, actual events, and empirical investigations is shown in Figure 3.

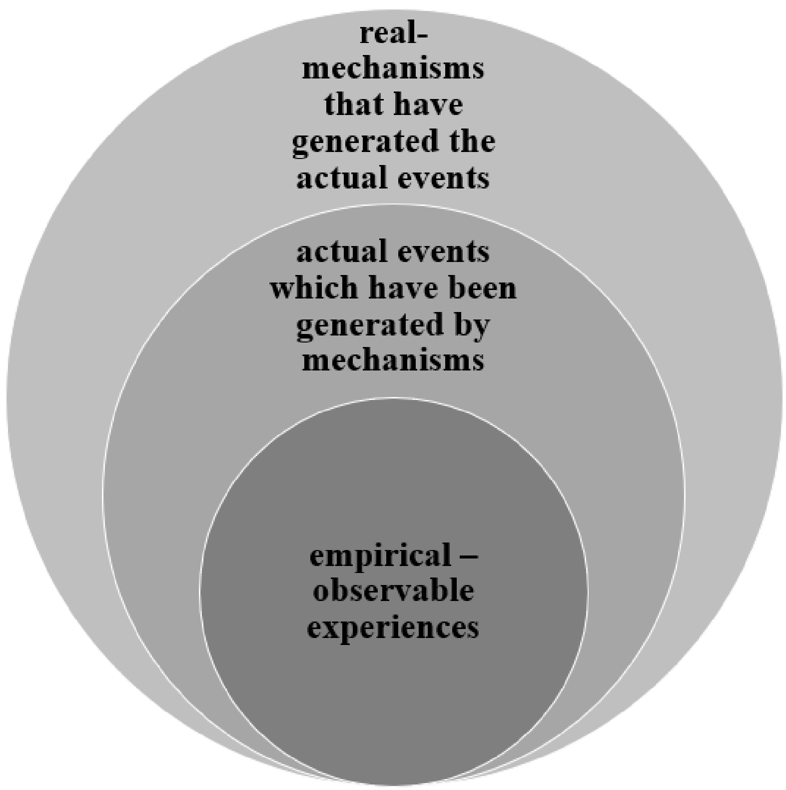


*Figure 3: Critical realism according to Bhaskar [7] (figure adapted from Mingers and Wilcocks [36])*

While other research philosophies exist that are used in IS research, such as positivism-interpretivism [22] or social constructivism [24], they do not consider the real world in that it generates actual events. Positivism-interpretivism refers to "explain and understand" as the main reasons for investigating a certain topic [22]. Social constructivism "characterizes knowledge as the sets of beliefs or mental models people use to interpret actions and events in the world." [24] Thereby, both philosophies miss the real-world mechanism phenomenon [7]. Besides science being eager to explain actual events as best as possible, the real world contains that many mechanisms that science is unable to understand and explain all of them, as required by positivism-interpretivism [22]. Further, science is unable to gain every knowledge that would be necessary to explain all real-world mechanisms [10, 24]. In contrast, CR considers the real-world mechanisms phenomenon and has been widely adopted in IS research [11, 35, 36]. Further, CR has been used to explain the results of the interaction "[…] between organizational context and management interventions to develop and implement strategic IS plans." [38].

Applying CR to social sciences (such as organizational and individual perspectives concerning IPS in hospitals) causes several conditions that have to be considered while conducting research. According to CR, real-world mechanisms are caused by human society and culture that are generated by human activities. Thereby, human society and culture are frequently changing and differ depending on region and time. Thus, research according to CR focuses on ex-post explanations rather than ex-ante predictions, as the structures that generate society and culture are too open and cannot be controlled using a laboratory-type setting [7].

By applying CR to the context of IPS in hospitals, digitalization as a real-world mechanism causes organizations to pursue the simplification of services as well as the increase of customer satisfaction [53]. Among other effects, digitalization triggers hospitals to simplify their navigational services and to increase patient satisfaction [53]. To provide those hospitals with useful insights for IPS adoption, this dissertation is framed by TOE framework, integrating the insights into technological, organizational, and environmental contexts [10]. For evaluating IPS in hospitals, mixed methods (by combining quantitative and qualitative measures) were used in a complementary fashion, as all results of the methods should contribute to at least one context of TOE framework. Further, such a complementary mixed-method approach is particularly suitable for CR research [46, 52]. The application of IPS in hospitals to CR is presented in Figure 4.

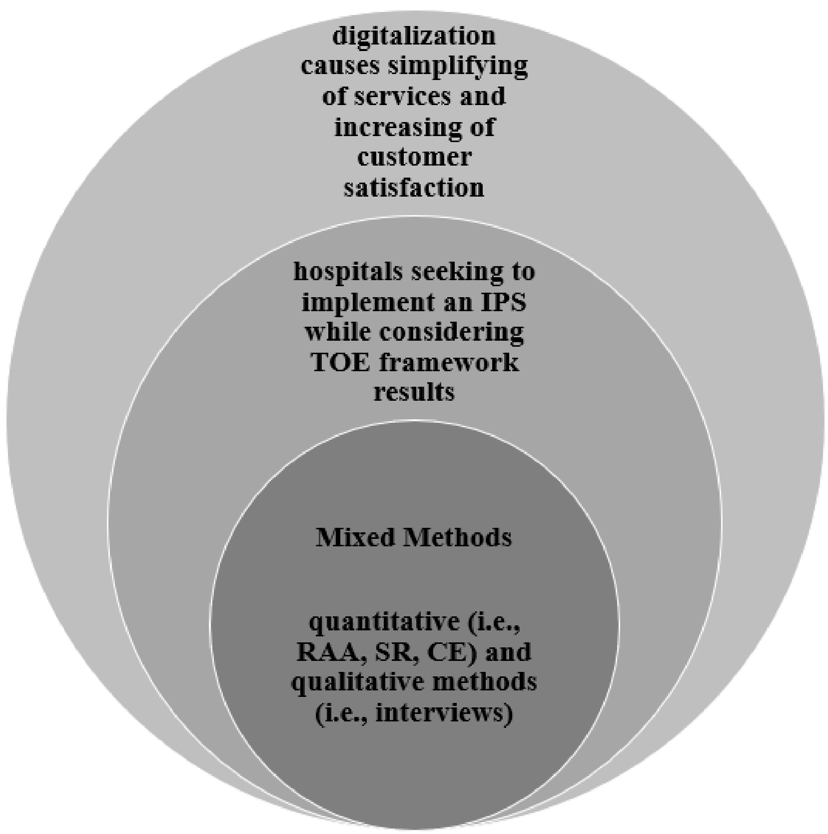


*Figure 4: IPS in hospitals in critical realism according to Bhaskar [7] (figure adapted from Mingers and Wilcocks [36])*

## 1.3 Mixed Methods in Technology Adoption Research in Healthcare

For technology adoption, mixed methods are appropriate that combine quantitative and qualitative measures [37]. To differentiate between certain mixed methods, Morse listed eight mixed-method designs that combine quantitative and qualitative measures using several focuses [37]. Further, Morse defines the eight mixed-method designs to be either inductive or deductive and conducted sequentially or simultaneously [37].

For contract tracing apps concerning COVID-19, Zimmermann et al. [54] designed a qualitative study by interviewing 110 individuals about their opinions towards tracing apps. Those contract tracing apps work like IPS in that individuals' positions are determined [48]. The insights of the interviews of Zimmermann et al. [54] were compared with newspaper contents in Germany. Ultimately, COVID-19 caused a significant demand towards tracing apps in general [54]. In a study that addresses patients, Irizarry et al. [23] conducted a phone survey with 100 community-dwelling adults. Then, those adults were assorted to focus groups to determine if patient portals are a useful tool for health care engagement [23]. Thereby, Irizarry et al. [23] used a qualitative method design that was supported by quantitative measures to generate and analyze focus groups in a subsequential, inductive theoretical drive fashion [23, 37].

Regarding physicians, Dahlhausen et al. [9] designed a qualitative study that was verified by quantitative measures [9, 37]. In their study, they conducted exploratory interviews to ascertain variables for an online survey addressing physicians' attitudes towards prescribable mHealth apps and implications for their adoption in Germany [9, 37]. In contrast concerning a quantitative study design that was supplemented by qualitative measures, Manojlovich et al. [33] provided a mixed-method research protocol with two phases [37]. The first phase contained a quantitative questionnaire that was evaluated using the healthcare information and management systems society's model [21]. The second and qualitative phase is divided into two parts and based on the results of phase 1, as communication technologies in certain hospitals are investigated. Thus, the study of Manojlovich et al. [33] is a sequential analysis that is inductive theoretical driven [37].

## 1.4 Research Concept

### 1.4.1 Research Framework and Methods

This dissertation adopts the TOE framework according to DePietro et al. [10] as the research paradigm to the context of IPS in hospitals. Thereby, TOE handles the whole process of information system (IS) innovations – "[…] from the development of innovations by engineers and entrepreneurs to the adoption and implementation of those innovations by users within the context of a firm" [5, 10]. For hospitals, such innovations are, among others, IPS [48, 54] or virtual reality [42]. According to TOE, the decision of whether to adopt a technological innovation is dependent on technological, organizational, and environmental contexts. For this, DePietro et al. [10], as well as Baker [5] provide measures for the respective contexts that are presented in Figure 5.

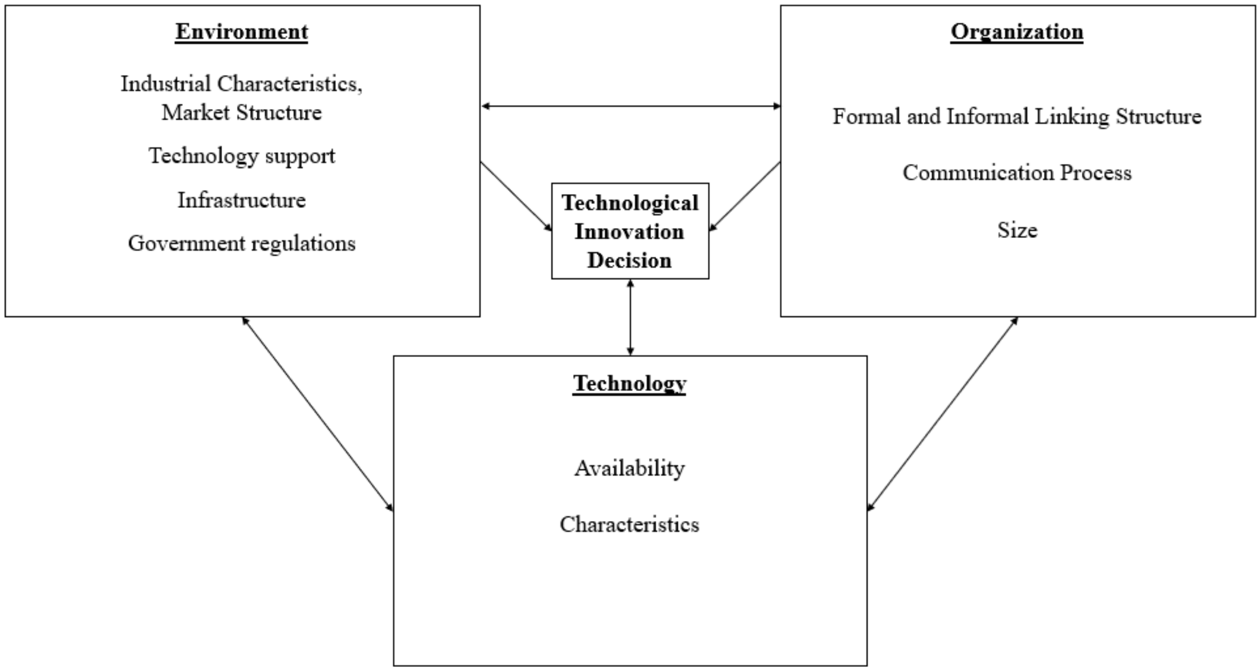


*Figure 5: Technology-Organization-Environment framework according to DePietro et al. [10]*

The peculiarity of TOE is that it is hardly been revised since its creation, due to its generic design [4, 5]. Simultaneously, the generic design of TOE requires adoption of the framework to a specific application context [4, 5]. However, as TOE is a framework using an organizational perspective [5, 10], the paradigm usually requires organizational data to contribute to the three contexts, besides simultaneously being limited due to the organizational data that is often not generalizable [4]. Thus, recent extensions of TOE recommend using quantitative measures, like methods to investigate the users' intention to use the technological innovation, in addition to qualitative methods that have been superficial for TOE [4].

Therefore, this dissertation considers TOE and its recent extensions for research by providing certain measures for the respective TOE contexts to investigate IPS in hospitals. For this, the RAA according to Fishbein and Ajzen [13] as a quantitative measure was used to identify potential IPS users' intention to use IPS in hospitals and their requirements towards it. Further, a SR according to Arksey and O'Malley [3] was conducted to gain knowledge about IPS in hospitals quantitatively. To achieve comparability of the findings of IPS in hospitals among each other and with IPS in other application scenarios, the IPS Evaluation framework according to Liu et al. [31] and Zafari et al. [53] was added to the SR. For investigating the organizational perspective of IPS in hospitals, interviews were conducted with IT representatives from different hospitals and different IPS developers to specify performance and content-related requirements for IPS in hospitals [50]. Then, those insights were used to evaluate controlled field experiments (CFEs) that have been conducted to test an IPS in a hospital scenario [50]. Figure 6 describes the assignment of those measures (RAA, SR, interviews, CFEs) to the respective TOE contexts.

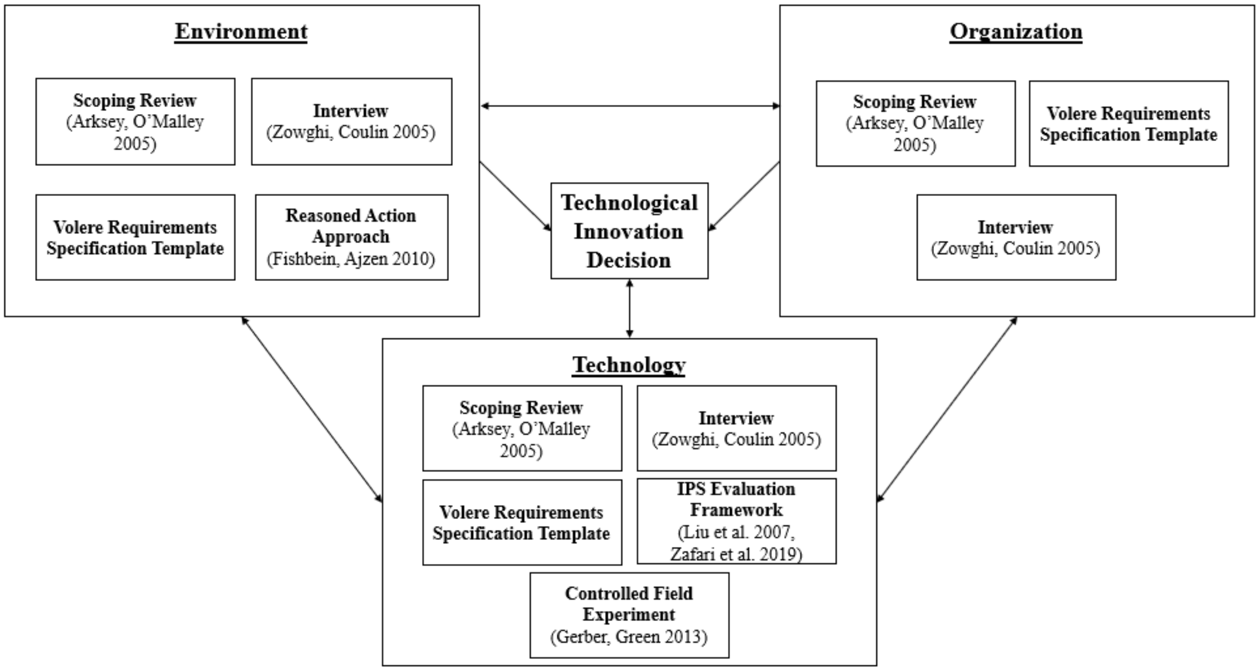


*Figure 6: Measures for TOE framework to evaluate IPS in hospitals*

Concerning the mixed method design propositions according to Morse [37], this dissertation is designed quantitative, as most of the qualitative measures concerning IPS (such as technologies and techniques) are already known [31, 53]. Hence, comparing different IPS approaches in hospitals and evaluating them in terms of performance is important. Further, large amounts of potential users should be investigated about their intention to use IPS in hospitals as those insights are more important measures than determining qualitative insights about IPS [2].

### 1.4.2 Research Process

For guiding this dissertation, TOE framework was added to the PPDF according to Barclay and Osei-Bryson [6]. PPDF "[…] provides a formal methodology for: (1) identification of project stakeholders, (2) elicitation and structuring of project objectives based on perspectives of the relevant stakeholders, (3) prioritization of project objectives, (4) elicitation and identification of measures that could be used to evaluate each project." [6]. Further, PPDF has been used to implement an IS and requires the implementation of the IPS in product environment as well as a functionality testing as measures for the project [6]. As both, TOE and PPDF, are generic in their design, the technological, organizational, and environmental contexts of TOE were applied to PPDF to be more precise in choosing appropriate measures to evaluate IPS in hospitals. The integrated PPDF-TOE framework is shown in Figure 7.

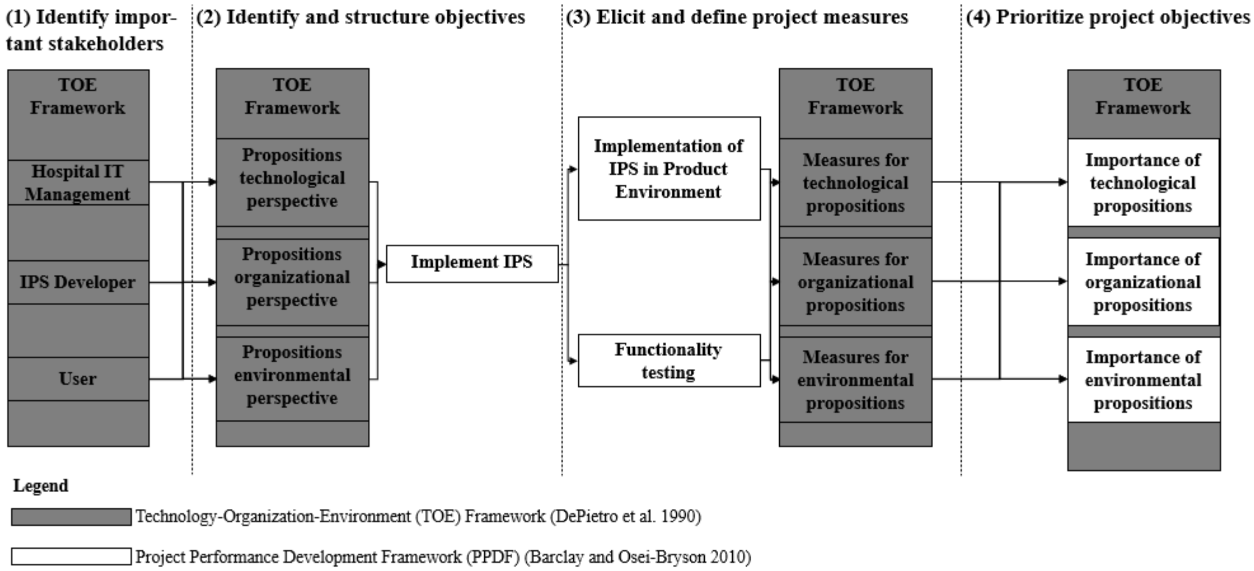


*Figure 7: TOE framework (according to DePietro et al. [10]) in PPDF (according to Barclay and Osei-Bryson [6])*

The integrated PPDF-TOE framework was then applied to the context of IPS in hospitals. First, Baker referred to developers, firms, and users as the most relevant stakeholders for the adoption and implementation of innovations [5]. Therefore, the stakeholders for IPS in hospitals are IPS users, hospital IT management, and IPS developers and solve the first PPDF task to identify important stakeholders [6]. Second, PPDF requires identifying and structuring objectives [6]. To gain knowledge about IPS in hospitals and to identify and structure objectives, quantitative and qualitative measures were conducted. First, the intention to use IPS in hospitals as well as requirements towards IPS were investigated by questionnaires. Those questionnaires were answered by hospital visitors and employees using the RAA according to Fishbein and Ajzen [13] as the methodology of the study (see section 2). Further, scientific literature databases were screened to learn about IPS technologies, application scenarios for IPS in hospitals, as well as their respective performance in hospital scenarios. The relevant studies from those databases were then reviewed using the method of SR (see section 3).

Overall, the investigation of the users' intention to use IPS in hospitals as well as their requirements [48] combined with the SR [47] showed that IPS are important for hospitals. Further, efficient IPS functions, sufficient IPS performances, and sufficient IPS operations conditions are important for proper operating [47, 48]. Then, the PPDF requires certain measures for the project's objectives, eg, for implementing the IPS and testing its functionality [6]. For IPS in hospitals, IPS functions, performance criteria, as well as operations conditions in hospitals were determined and evaluated as measures for the objectives (see section 4). Finally, the evaluated measures had to be prioritized to provide recommendations for IPS development from TOE perspectives (see section 1.5.3). The process of the dissertation with the aim to evaluate IPS in hospitals is shown in Figure 8.

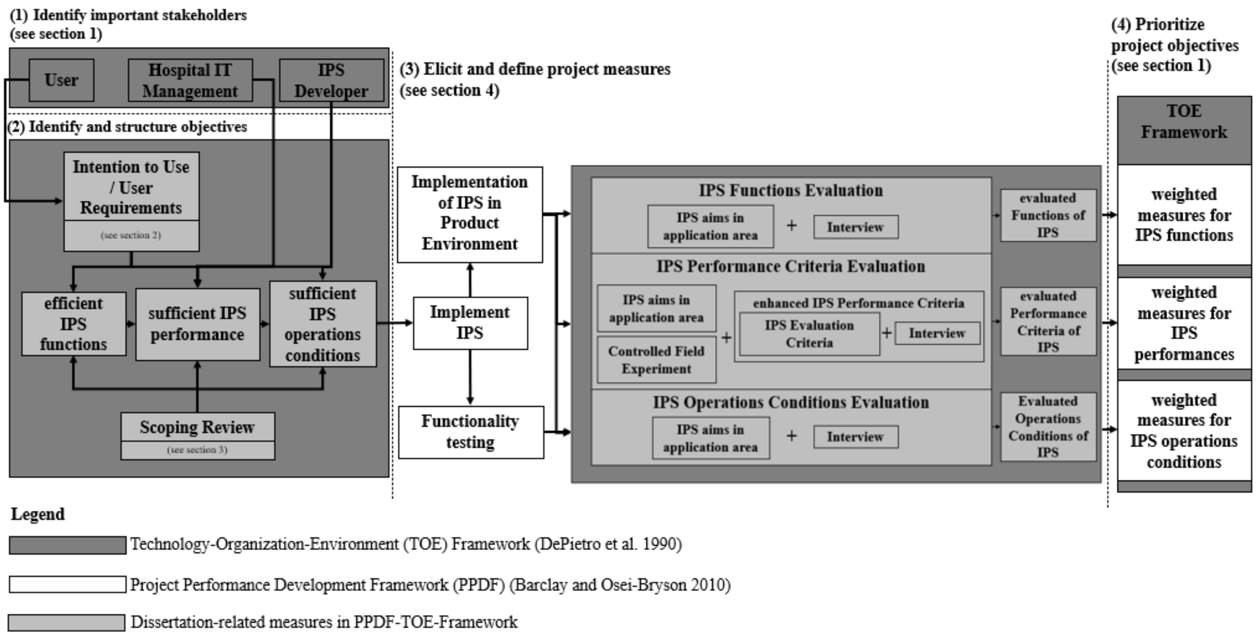


*Figure 8: Procedure of the Dissertation (applying TOE in PPDF for evaluating IPS in hospitals)*

Regarding the mixed-method propositions of Morse [37], Figure 8 depicts that, besides the quantitative design of this study, qualitative methods are used to validate the propositions of the quantitative studies. In particular, expert interviews were conducted that were based on the results of the quantitative investigations, leading to a sequential research process that is deductive theoretical driven. Thereby, the study design and process of this dissertation align with general propositions of CR, as the research philosophy is appropriate for ex-post explanations and deductive analyses [7]. Those kinds of explanations and analyses have been conducted in this dissertation.

## 1.5 Research Results

### 1.5.1 Factors Influencing the Intention of Actors in Hospitals to Use Indoor Positioning Systems: Reasoned Action Approach[1]

For determining the intention to use IS, several methodologies exist that can be applied to healthcare contexts of which the RAA is one of those methodologies [19]. Thereby, RAA is particularly suitable to investigate an individual's intention to use an information system [25] and thus for IPS, respectively. According to RAA, an individual's intention to use is dependent on: (1) the attitude an individual has towards the IPS, (2) perceived norms as opinions of other individuals that are important to the respective individual about the behavior in question (ie, the intention to use IPS in hospitals) and (3) perceived behavioral control as the actual control the individual perceives she/he has about performing the behavior in question (ie, the intention to use IPS in hospitals). Further, Fishbein and Ajzen [13] recommend using control variables that are dependent on the application scenario (ie, navigation in hospitals, personal innovativeness) to verify the results.

[1] The article is published in the Journal of Medical Internet Research (JMIR), Vol. 23, Iss. 10, e28139 [48].

We applied the RAA to the context of IPS in hospitals by providing questionnaires that were answered by 323 hospital visitors and 304 hospital employees. The results revealed that both, hospital visitors and hospital employees, intend to use IPS in hospitals. While attitude and perceived norms were significant predictors for the intention to use for both, hospital visitors and hospital employees, perceived behavioral control was relevant for hospital employees only. Further, control variables influenced the intention to use IPS in hospitals and their respective predictors. First, personal innovativeness as the individuals' familiarity with new technologies and information systems significantly influenced attitude and perceived norms of hospital visitors and the intention to use for hospital employees. Second, spatial abilities as the individuals' navigational skills while moving through buildings were investigated. Those spatial abilities were relevant attendances for the intention to use for hospital employees.

Concerning TOE, the study has proven that users generally intend to use IPS in hospitals. Therefore, we recommend developing them. Further, we specified user requirements towards IPS in hospitals as well as functions IPS should have (see section 2). Those results contribute to the environmental context of TOE.

### 1.5.2 Indoor Positioning Systems in Hospitals: A Scoping Review[2]

To determine recent IPS technologies and to evaluate existing IPS in hospitals, a Scoping Review according to Arksey and O'Malley [3] was conducted. For this, scientific literature databases (Scopus, AISeL, IEEE) were screened concerning certain IPS evaluation criteria that were adapted from Liu et al. [31] and Zafari et al. [53]. They are IPS localization technologies, localization techniques, prediction improving methods for IPS, as well as the evaluation and limitations of IPS in hospitals [31, 53]. The review was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework [30]. In total, 404 articles were determined through the databases, with 301 excluded from the study due to duplicates and articles not meeting the defined inclusion/exclusion criteria in the SR. The remaining 103 articles were investigated in-depth, from which 38 studies were included in the review. According to the SR, various IPS technologies (such as Wi-Fi, BLE) were applied using several IPS techniques and prediction improving methods. Additionally, those 38 articles were reviewed using IPS evaluation criteria that were provided by Liu et al. [31] and Zafari et al [53].

The results reveal that, in general, the algorithm of the IPS is more relevant than the raw technology choice to improve overall IPS performance, thus supporting the insights of van Haute et al. [44]. Specifically, the results show that the prediction improving method is mandatory for improving overall IPS performance. Further, the study contains competitive comparisons of IPS in hospitals using criteria according to Liu et al. [31] and Zafari et al [53], providing certain details about the strengths and weaknesses of hospital-IPS development.

Concerning TOE framework, the SR contributes to the technological as well as to the organizational context. Regarding IPS technologies, the SR provides a detailed evaluation of IPS technologies in hospitals in that the different studies have been compared using a well-investigated IPS evaluation framework [31, 53]. Simultaneously, the SR identified several application scenarios for IPS in hospitals that serve the organizational context of TOE and are fundamental for developing key IPS functions (see section 3).

[2] The article has been accepted for publication in the DIGITAL HEALTH journal [47].

### 1.5.3 Determining Design Criteria for Indoor Positioning System Implementation Projects in Hospitals[3]

Ultimately, after determining the intention to use IPS in hospitals by users, their requirements, as well as IPS technologies in hospitals and their performance, the results were adopted to hospitals-IPS contexts. For this, the TOE framework was adopted to the PPDF to determine design criteria for IPS implementation projects in hospitals.

First, the results of RAA and SR were used to define requirements and functions for IPS in hospitals. Those functions and requirements were mandatory for conducting expert interviews [55] with 5 representatives of hospital IT management from different hospitals and 5 IPS developers from different companies. Next to the user functions and requirements, the interviewees were asked to estimate IPS cost, to rank the IPS evaluation criteria according to Liu et al. [31] and Zafari et al. [53]. Further, the experts had to assess operations conditions that are important to consider for proper operating of IPS in hospitals. According to our experts, operations conditions were considered less important in the overall evaluation of IPS in hospitals, compared to IPS functions and IPS evaluation criteria.

Second, we conducted CFEs [18] to test an ultrasound-based IPS for operating in a hospital. For this, we provided an experimental setup as well an evaluation of the ultrasound-based IPS using the IPS evaluation framework [31, 53]. This framework was enhanced by statements of hospital IT management and IPS developers about the importance (ie, ranking) of the criteria of the IPS evaluation framework [31, 53]. Further, we compared our results with the IPS evaluation framework findings of those 38 studies included in the SR.

Third, we determined certain design criteria due to the expert interviews, CFEs, and SR-related comparisons. As for IPS functions, our experts require IPS in hospitals to be usable by individuals with disabilities, such as visual or hearing impairments. For IPS performance evaluation, they state that the IPS should be as mature as possible when it is to be implemented in hospitals as later adjustments of the IPS are expensive and costs are relevant for adoption. Further, our experts expressed concerns about the sufficient functioning of IPS in hospitals due to specific environmental factors, such as radiation. These should be urgently taken into account during development. Our CFEs and the SR-related comparisons indicate that the hospital environment is indeed important for the overall IPS performance.

For TOE framework, this study provides several propositions. Concerning the organizational context, operations conditions for IPS in hospitals were specified and a cost-benefit analysis of functions for IPS in hospitals was conducted, using the experts' perspectives. Regarding the technological context, an enhanced IPS evaluation framework was introduced to TOE, as well as an experimental setup for IPS (in hospitals).

### 1.5.4 Evaluating Indoor Positioning Systems in Hospitals using Technological, Organizational and Individual Perspectives

To evaluate IPS in hospitals using TOE framework, this dissertation provides several measures to do so. Thereby, recent extensions of TOE framework have been considered [4], using quantitative (RAA) and qualitative methods (SR, requirement specification, enhanced IPS evaluation framework, interviews, CFEs) for the development of IPS measures. The results of the studies included in this dissertation concerning TOE framework (see section 2-4) are summarized in Figure 9.

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[3] The article is currently under review for presentation at the 30th European Conference on Information Systems (ECIS) 2022 in Timisoara, Romania [50].

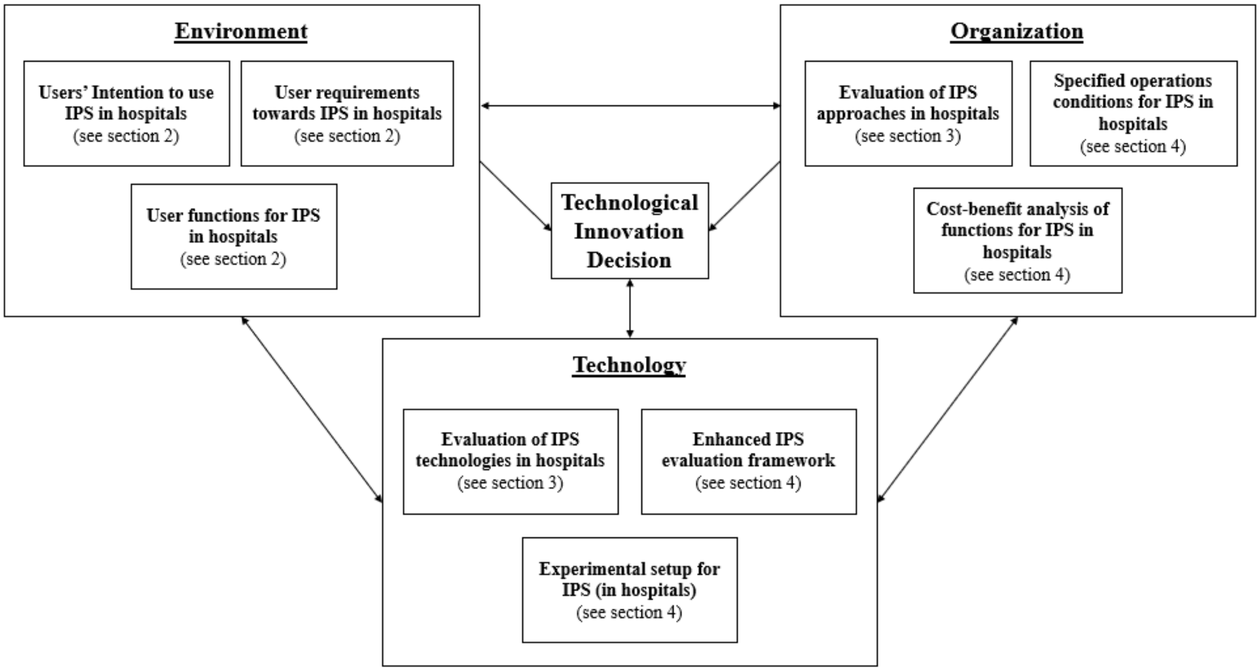


*Figure 9: Results for TOE framework by evaluating IPS in hospitals*

## 1.6 Discussion

This dissertation examined organizational and individual perspectives regarding IPS in hospitals by adopting the TOE framework to this application scenario. To do so, a mixed-method design was chosen to adopt the TOE to the scenario and to provide propositions to TOE's contexts.

By successfully conducting quantitative and qualitative evaluations within TOE, this dissertation aligns with recent extensions of TOE that require such a study design [4]. Further, the results reveal that a certain demand for IPS in hospitals exists, due to (1) high and significant intentions to use IPS in hospitals by users, (2) various applications of IPS in hospitals that were determined by the SR, and (3) propositions from experts. Thus, the results support the assumptions of market studies [1, 34] and research [2] in that IPS implementation is important for hospitals.

First, regarding the individual perspective (that mainly serves the environmental context of TOE), the users' high and significant intention to use does not immediately lead to the adoption of such systems by hospitals. This proposition results from the fact that lesser IPS have been implemented in hospitals than expected [1, 16, 34]. In terms of users of IPS and RAA as the method to investigate their intention, this phenomenon is explained by the intention-behavior gap [13]. According to this gap, the intention to use is the most important variable to determine actual behavior [13]. Nonetheless, besides high and significant intentions to use, individuals may deviate from their intention to use in that the actual behavior is different than expected [13]. To address this phenomenon and reduce its impact, Fishbein and Ajzen recommend using control variables to restrict the intention to use [13]. Such variables have been adopted as spatial abilities and personal innovativeness for IPS in hospitals, which allowed additional statements about the intention to use to be made, but actual use is still not guaranteed. It is likely that other variables also influence actual use, the number of which is so large that they cannot be explained by science [7, 13]. In terms of IPS in hospitals, COVID-19 is such a variable [13] (also known as "real-world mechanism" in CR [5, 10]), as it caused a shift in demand for location-based services [54] in that IPS can contribute to preventing the spread of diseases [48]. Therefore, IPS studies that are conducted after this dissertation might reveal other results in terms of demands towards IPS.

Second, by considering the organizational perspective and context of TOE, the results also reveal that the potential benefits IPS could provide by containing certain functions are limited. Our experts assessed some IPS functions (such as navigation for visually impaired individuals [53]) more important than others (such as treatment management [41]) due to the cost that certain function causes. This proposition is contrary to IPS studies that have realized functions that were estimated too expensive by the interview experts (such as treatment management [41]).

Third, regarding the technological context of TOE, the results show that the performance of IPS in hospitals is dependent on the hospital environment (see section 3,4). This proposition supports the insights of Liu et al. [31] and Zafari et al. [53] who stated that the environment is important for IPS in general. Especially radiation within the hospital is known to influence the performance of IPS [53] (see section 3,4), displaying the need to investigate IPS in their real-world environment to better understand their mechanisms [53]. This proposition is supported by CR [4, 5, 10]. Further, the results of the CFEs show that our ultrasound-based IPS could perform better in terms of accuracy. According to IPS studies [31, 53], ultrasound-based IPS can perform more accurately in general, but we performed quite well by comparing our results to those of other IPS in hospitals (see section 4.5). Thus, this dissertation supports the propositions of van Haute et al. [44] in that IPS algorithms are more important for sufficient IPS than the raw technology choice.

## 1.7 Theoretical and Managerial Implications

Concerning the research question posed, this dissertation uses the TOE framework in a CR context to answer it. To do so, organizational and individual perspectives have been addressed by adopting quantitative and qualitative measures. Thus, this dissertation proves the applicability of TOE and CR framework to the context of IPS in hospitals and provides implications for the quantitative and qualitative measures used. Concerning TOE (which is known to be a more generic framework [4, 5]), future TOE research benefits from this dissertation by receiving suggestions for methods to conduct TOE due to investigating IPS in hospitals. Regarding CR, this dissertation confirms that actual events are indeed caused and influenced by real-world mechanisms, as the gap between expectation and reality of IPS implementations in hospitals shows [1, 16, 34]. To investigate the relationships within CR, mixed methods were used that were both, quantitative and qualitative. Such mixed methods are important for CR research [46, 52] and to determine design criteria for IPS [20]. As quantitative measures, RAA, SR, and CFEs were applied to the context, while interviews were purposed as qualitative methods for IPS in hospitals. Hence, this dissertation provides the above theoretical implications, as it considers recent extensions of TOE that recommend using quantitative and qualitative methods for the framework [4]. Further, this research provides a guideline for applying TOE to certain contexts, such as IPS in hospitals, by operationalizing it using PPDF [6]. Next to TOE, PPDF benefits from this dissertation, as the PPDF itself is vague in terms of certain measures for IS implementation [6]. As both frameworks, TOE and PPDF, require the respective framework to be adopted to a specific application scenario, this dissertation shows how applying to an application scenario could be handled. For this, RAA, SR, CFEs, interviews, TOE, and PPDF can be combined in a meaningful way to investigate the implementation of an IS within an application scenario, such as IPS in hospitals. Further, concerning theoretical implications for the respective methods of the studies, this dissertation proposes:

1. that RAA is appropriate to investigate the users' intention to use IPS in hospitals. Further, we designed and conducted questionnaires concerning IPS in hospitals that can be used by others for

such purposes (see section 2.7.1). With our RAA findings, we also contribute to spatial ability and technology adoption research in general (see section 2.6).

2. SRs to be sufficient to examine IPS in hospitals and the IPS evaluation framework to be adequate to compare them. The findings contribute to general IPS research by providing IPS technologies, techniques, prediction improving methods, evaluation results, and limitations of IPS in hospitals. Further, literature review research benefits from the SR, as a search strategy and standardized data extraction form for IPS literature reviews are provided.
3. CFEs and interviews to be adequate to investigate IPS in hospitals on an organizational level. As our CFEs' results were comparable in performance to those of the SR (see section 4.5), we provide an experimental setup for testing IPS that can be adopted by other IPS studies.
4. Further, we contribute to our general understanding of implementing IPS in an application area from an organizational perspective. We do so, as we designed a procedure for interviewing experts about their opinion towards IPS in the application area, ie, IPS developers and hospital IT management for IPS in hospitals.

Next to theoretical implications, this dissertation provides managerial implications that are as follows:

1. Due to our RAA results and the users' intention to use IPS in hospitals, we highly recommend hospitals to implement IPS and IPS developers to further invest in IPS enhancements. As we also found that spatial abilities and personal innovativeness were significant and important predictors for the intention to use (see section 2.5), we suggest IPS developers: (1) keep the IPS simple, (2) ensure proper operating of the IPS, and (3) consider sufficient accuracy for the tasks given. Further, perceived behavioral control is a significant predictor for the intention to use concerning hospital employees. Thus, we propose hospitals involve their employees in the processes of determining design criteria for and implementing IPS in hospitals. We do so, as the significance indicates that employees do not intend to use the IPS unless they recognize benefits from using it.
2. The findings of the SR reveal that the algorithm of the IPS is more important than the raw technology choice, thereby supporting the proposition of van Haute et al. [44]. Thus, IPS developers should focus on their algorithm for enhancing their IPS instead of using a different technology. To do so, the SR provides an overview of certain prediction-improving methods that can be used to improve the algorithm of an IPS (see section 3.4). Further, hospitals seeking to implement an IPS benefit from the SR. Those hospitals receive a review of IPS in hospitals that contains various IPS technologies, techniques, and prediction improving methods as well as a comparison of IPS performances in hospitals. Those propositions can be used by hospitals to facilitate IPS implementation.
3. The applied PPDF-TOE framework for IPS showed that IPS functions, performance criteria, and operations conditions evaluation are appropriate dimensions for evaluating IPS (in hospitals). Specifically, on an organizational level, the study provides (1) IPS functions using cost-benefit perspectives by hospital IT management and IPS developers, (2) a ranking of the IPS evaluation criteria [31, 53], and (3) the determination of IPS operations conditions that have to be considered in hospital setups (see section 4.5). Further, as our CFEs performed similar to those in the SR, we provide certain hardware specifications that can be used for IPS testing by IPS developers (see section 4.4).

## 1.8 Limitations and Future Research

Like with any research, this dissertation is subject to limitations. First, on a theoretical level, the methods chosen for evaluating IPS in hospitals that were applied to TOE framework resulted in specific design criteria for IPS in hospitals. As TOE framework is generic [4, 5] and should be conducted using quantitative and qualitative measures [4], the results of TOE are dependent on the methods chosen. This indicates that choosing other methods, such as group discussions between our IPS experts, could lead to different results.

Furthermore, regardless of the clear indications that there is widespread interest in implementing IPS in hospitals, the implementation of IPS has largely not yet been accomplished, as recent market studies report [1, 34]. Likely, this lack of implementation is at least partly due to COVID-19 [48], with a general interest in tracing apps having increased as a result of COVID-19 [54]. Hence, further investigation into the widespread adoption of tracing apps or IPS in the post-COVID-19 era would be interesting. Additionally, this phenomenon supports CR as the research philosophy for this dissertation in that COVID-19 as a real-world mechanism actively influenced actual events in terms of implementing IPS in hospitals [11, 38, 48, 54].

Regarding the results of this dissertation, future research should focus on the determined design criteria that could be verified by implementing an IPS that is based on those design criteria. Then and to tackle limitations of the methods chosen (such as the intention-behavior gap for RAA [13]), our hospital visitors and employees can be surveyed about their actual use of IPS in hospitals. Further, as our experts addressed data protection regulations (see section 4.5) as concerns towards IPS, they should be considered for IPS research in general. Additionally, design science refers to other evaluation methods that could be used to investigate IPS in hospitals and related design criteria in future studies, such as black-box testing [20].

Concerning the practical level of IPS, this dissertation addresses hospitals as the mere application scenario, whereas other application scenarios are important as well. First, IPS are indeed dependent on their environment, as Zafari et al. proposed [53]. They are dependent, as this dissertation reveals that hospitals' surroundings influence IPS performance (see section 4.5). Thus, future IPS research should address other applications scenarios than hospitals. For instance, airports [53] should be investigated, as the radiations that are emitted by various scanners that are present due to personal security could significantly influence IPS performance. Second, as the algorithm of the IPS is more important than the mere choice of an adequate IPS technology [44], future studies should focus on improving IPS performance. The performance is important as eg, hardware stores [31] need a high IPS accuracy to successfully track their assets. One experimental setup in this regard could aim to achieve a position determination within the centimeter range, so that, for example, certain screws in a shelf can be found sufficiently. Next to IPS in hospitals, future research could use this dissertation’s process to investigate the potential implementation of other IS innovations in hospitals, and the proposed methods to determine design criteria for them. One such innovation could be virtual reality [42].

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# 2 Factors Influencing the Intention of Actors in Hospitals to Use Indoor Positioning Systems: Reasoned Action Approach[4]

*Johannes Wichmann and Michael Leyer*

**Abstract**

**Background:** Indoor positioning systems (IPS) have become increasingly important for several branches of the economy (eg, in shopping malls) but are relatively new to hospitals and underinvestigated in that context. This research analyzes the intention of actors within a hospital to use an IPS to address this gap.

**Objective:** To investigate the intentions of hospital visitors and employees (as the main actors in a hospital) to use an IPS in a hospital.

**Methods:** The reasoned action approach was used, according to which the behavior of an individual is caused by behavioral intentions that are affected by (1) a persuasion that represents the individual's attitude toward the behavior, (2) perceived norms that describe the influence of other individuals, and (3) perceived norms that reflect the possibility of the individual influencing the behavior.

**Results:** The survey responses of 323 hospital visitors and 304 hospital employees were examined separately using SmartPLS 3.3.3. Bootstrapping procedures with 5000 subsamples were used to test the models (one-tailed test with a significance level of .05). The results show that attitude ($\beta$=.536; $P$<.001; $f^2$=.381) and perceived norms ($\beta$=.236; $P$<.001; $f^2$=.087) are predictors of hospital visitors' intention to use an IPS. In addition, attitude ($\beta$=.283; $P$<.001; $f^2$=.114), perceived norms ($\beta$=.301; $P$<.001; $f^2$=.126), and perceived behavioral control ($\beta$=.178; $P$=.005; $f^2$=.062) are predictors of hospital employees' intention to use an IPS.

**Conclusions:** This study has two major implications: (1) our extended reasoned action approach model, which takes into account spatial abilities and personal innovativeness, is appropriate for determining hospital visitors' and employees' intention to use an IPS; and (2) hospitals should invest in implementing IPS with a focus on (a) navigational services for hospital visitors and (b) asset tracking for hospital employees.

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## 2.1 Introduction

Hospitals are characterized by high levels of physical movement, with a constant stream of temporary visitors (patients and related visitors), personnel, and mobile technical equipment operating in different locations. While efficiency is a concern, it is also of the utmost importance to ensure high levels of hygiene to avoid contamination and the spread of disease, a necessity highlighted by the COVID-19 pandemic. Consequently, preventing the spread of disease by improving hygiene [1] has been the subject of numerous studies [11, 29]. Indoor positioning systems (IPS) can support hospitals' efforts to improve hygiene for visitors and employees in three main ways. First, IPS in hospitals can facilitate wayfinding [69] and support measures against hospital-related infections, such as social distancing [19, 64]. Second, IPS can help employees find hospital assets [60] and enable patients to move through different departments [39]. Third, IPS can be used to monitor patients in need of assistance (eg, those with dementia) [32].

Until now, the market penetration for IPS in hospitals has been low because of high implementation costs—roughly US $10200 for approximately 9290 m² [41]. However, as radio-frequency identification tags and Bluetooth beacons have become cheaper, implementing IPS in hospitals is more attractive for hospital management [12]. Commercial implementations of IPS in hospitals in Germany [35] and the United States [57] provide examples of growing interest. Nonetheless, when assessing the costs and benefits, it is important to consider potential user acceptance issues, as high usage rates are necessary to obtain the full benefits of IPS.

Research on the adoption of health care tracking apps has shown the importance of acceptance, notably in the context of COVID-19 [49]. The results highlight the importance of functional and trust-related factors in the use of and intention to use such apps [65]. Some studies have applied model-driven approaches, such as the technology acceptance model [15, 16], to different IPS contexts [7]. However, in the hospital context, the only relevant study is that of Anagnostopoulos et al [5], who investigated the IPS needs of employees at Geneva University Hospital.

To investigate the intention of actors in hospitals to use IPS, we adopted the well-established reasoned action approach (RAA) as a causal model to identify relevant influencing factors. The RAA identifies reasons for a specific behavior by considering behavioral, normative, and control beliefs [22]. We surveyed 323 hospital visitors and 304 hospital employees in Germany. We set up a structural equation model (SEM) for both groups that includes factors relevant to the intention to use an IPS.

Our results contribute to understanding which factors influence the intention of actors (ie, hospital visitors and employees) to use systems or applications (ie, IPS) in the health care management context. We show that the RAA, extended to include spatial abilities, can explain the intentions of two major stakeholder groups to use systems in the context of health care management. Hospitals wishing to improve hygiene can apply these insights to encourage IPS usage. This will help tackle a range of issues, from the threat of multiresistant germs to restrictions on hospital visitor numbers during a pandemic. Therefore, we recommend that hospitals invest in the implementation of IPS, taking stakeholder-specific requirements into account.

This article is organized as follows: section 2.2 and section 2.3 clarify the theoretical background to the research and introduce the hypotheses and research model. Section 2.4 describes the materials and methods, and section 2.5 presents the results, which are discussed in section 2.6. Section 2.7 concludes the research, clarifies its implications, and provides an outlook for further investigations.

## 2.2 Theoretical Background

### 2.2.1 Indoor Navigation/Indoor Localization

An IPS determines the specific position of an individual or an asset [14] using an algorithm that estimates the position of a mobile client. Figure 10 shows how such connections can be established in a hospital setting [51] using a mobile device [52], a tag (ie, attached to a wheelchair), and a wristband [56]. These devices are connected by a set of reference points (ie, routers [46]) within a predefined area [18]. This allows different localization techniques such as Bluetooth or Wi-Fi to be combined with calculation principles to determine specific positions. Frequently used calculation principles are triangulation (represented here by the three circles) and trilateration (represented by the triangle), which use the received signal strength indication of the relevant localization technique [36]. An IPS of this type can be used to track patients in urgent care [39] or to locate insulin pumps [59], ultimately reducing waiting times and redundant activities.

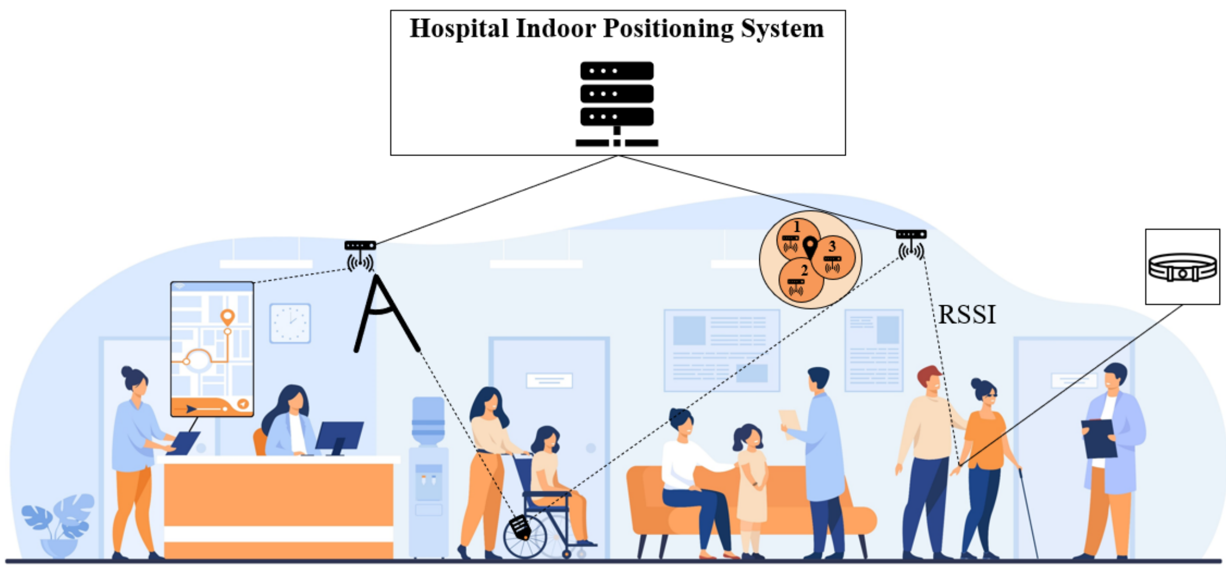


*Figure 10: Functional setup of an exemplary positioning system in a hospital [18, 36, 46, 59].*

### 2.2.2 Research on Indoor Navigation/Indoor Localization in Hospitals

Navigation applications allow the tracking of individuals by connecting localization data with personal data [17]. Research on health care tracking apps has shown the importance of social [49] and behavioral factors [49, 65] in relation to usage rates and intention to use. For example, research on COVID-19 apps has established that trust and privacy [4, 65, 72], as well as voluntary and temporary use, are important factors in acceptance [72]. In addition, a lifestyle that prioritizes hygiene has been identified as a major predictor of using a COVID-19 app, although evidence from Singapore suggests that demographics and situational characteristics are less relevant [53]. Although this previous research has identified factors that may be relevant, it focuses on general app usage. Therefore, we extend it by introducing a specific spatial and organizational context, namely the use of IPS in hospitals.

Model-driven approaches have been adopted in IPS research to account for the navigational requirements of users [7, 8]. For example, Arning et al [7] applied the technology acceptance model [15, 16] to an IPS that operates using a screen (eg, a smartphone) and a pico-projector. They found strong evidence that disorientation is the most important predictor of screen and projector acceptance. However, their research was limited to young people (ie, university students between the ages of 21-28 years) and may not be generalizable to other age groups. It should also be noted that the technology acceptance model does not include social influences, which are likely to be an important predictor for intention to use an IPS [62].

Within the hospital context, the only relevant study is that of Anagnostopoulos et al [5], who investigated the IPS needs of staff at Geneva University Hospital. They identified five key features of an app: (1) it should show the trajectory toward a destination on a map; (2) it should consider the mobility capabilities of users; (3) it should protect the individual's privacy; (4) it should estimate the position accurately; and (5) it should not require an internet connection to function properly. However, as these results were obtained from a specific case study, they may not be generalizable to users in other contexts.

### 2.2.3 The Reasoned Action Approach

The RAA is a well-established psychological approach based on the theory of reasoned action [2, 3, 20, 21], which is widely accepted in psychological studies [6] and is appropriate for ascertaining individual behavior. According to the RAA, individual behavior is caused by behavioral intentions that are rooted in (1) a persuasion that influences the individual's attitude toward the behavior; (2) perceived norms that describe the influence of other individuals; and (3) the opportunity for the individual to affect the behavior, referred to as perceived behavioral control [22]. Figure 11 represents the RAA in greater detail. An individual's attitude regarding a certain behavior is influenced by his or her beliefs concerning the characteristics and attributes related to the behavior. Thus, an attitude is affected by individual consequences that emerge through assessments of whether or not the behavior is desirable. Therefore, the individual is influenced by whether the behavior is endorsed or opposed by other individuals or groups (those who are most important to her or him in terms of the relevant behavior). The aggregation of motivation and perception assessments for all relevant referent groups is referred to as perceived norms [3, 20, 21]. Perceived behavioral control determines whether an individual is capable of or directly controls a specific behavior. It is defined by control beliefs that reflect the individual's key personal or situational aspects in relation to the behavior. Ultimately, performing a specific behavior involves the comparison and selection of attitudes, perceived norms, and perceived behavioral controls associated with each of the alternative behaviors in the choice set [55]. Considering these factors together makes it possible to ascertain the likelihood of an individual performing a specific behavior.

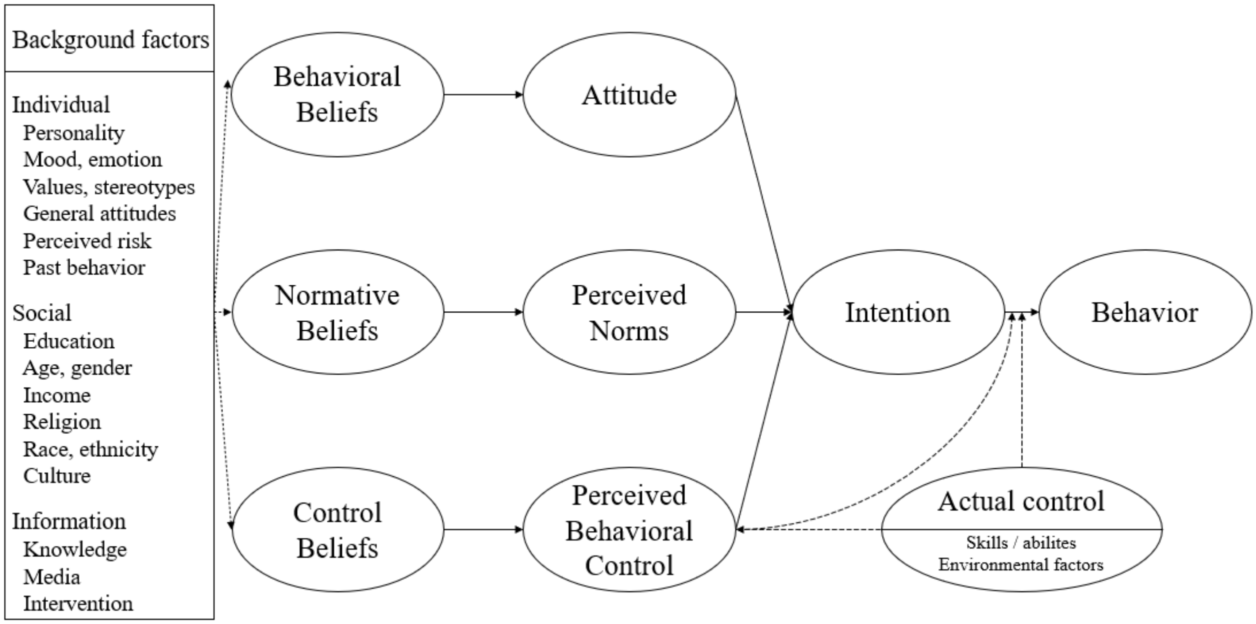


*Figure 11: The reasoned action approach (RAA) according to Fishbein et al [20].*

## 2.3 Hypotheses and Research Model

The RAA is a framework that has to be adjusted to a specific context [22]. In this study, we apply it to the hospital context to predict intention to use an IPS. First, behavioral beliefs are important for ascertaining the value that an individual perceives in using an IPS. These beliefs cover whether an IPS is perceived as helpful in finding the right location or tracking an object. The positive or negative feelings an individual has toward using an IPS in a hospital (the individual's attitude) are rooted in those beliefs. For the purposes of this study, positive feelings are taken as how the individual feels, as it is the individual who determines whether an IPS is beneficial, satisfactory, relevant, and pleasant to use [28]. The RAA then states that if an individual's attitude toward an IPS is positive, the individual will have a higher intention to use the IPS [22, 55]. These considerations lead to the following hypotheses:

*H1: The higher the behavioral beliefs concerning the use of an IPS in a hospital, the more positive an individual's attitude regarding the IPS.*

*H2: The more positive an individual's attitude concerning the use of an IPS in a hospital, the higher the intention to use the IPS.*

Second, in line with RAA research, we represent the attitudes of other relevant individuals and groups as normative beliefs (subjective norms) [22, 23, 34]. For hospital visitors, we define family and close friends as relevant social influence groups. For hospital employees, we define immediate colleagues, colleagues in related functional areas, and superiors as relevant influence groups. Normative beliefs generate perceived pressure or motivation, according to whether the individual thinks using an IPS is supported or urged by the reference groups. As implementing an IPS system can be very complex, and the demands on the time and effort of the individual may be high [70], hospital visitors and employees are likely to seek insights from other individuals and groups. In terms of the RAA, the more positive the perception of support from the reference groups, the higher the intention to use an IPS in a hospital. These considerations lead to the following hypotheses:

*H3: The higher the normative beliefs concerning the use of an IPS in a hospital, the more positive an individual's perceived norms regarding the IPS.*

*H4: The more positive an individual's perceived norms regarding the use of an IPS in a hospital, the higher the intention to use the IPS.*

Third, it is necessary to investigate what facilitates or obstructs an individual's use of an IPS in a hospital. Two of the most critical success factors in relation to information technology projects in hospitals considered are: (1) the complexity of the system and (2) the explanation of how to access it [54]. For the purposes of this investigation, the capability of an individual to use an IPS is dependent on those success factors, which affect whether the individual perceives that she or he controls the new IPS. The individual has to be able to use the IPS under guidance to confirm these control beliefs [13]. Intention to use the system is positively influenced by a higher perceived behavioral control [22, 55]. These considerations lead to the following hypotheses:

*H5: The higher the control beliefs concerning an IPS in a hospital, the more positive the perceived behavioral control of an individual regarding the IPS.*

*H6: The higher the perceived behavioral control in terms of an IPS in a hospital, the higher the intention to use the IPS.*

The navigational skills of the individuals have to be examined to determine confidence in the use of IPS in a hospital (in terms of perceived behavioral control) [50]. Therefore, navigational skills are used here to validate the connection between spatial abilities and intention to use an IPS in a hospital, as well as the connection between spatial abilities and perceived behavioral control. Yao et al. [66] determined that spatial abilities are an important predictor of planning to use a navigational application in outdoor environments. Accordingly, we assume that individuals who are good at navigating through buildings without assistance will be confident about using an IPS in a hospital but will not need to use an IPS urgently. Therefore, we differentiate between hospital visitors and hospital employees. For visitors, we investigate their spatial abilities as a whole, formulating the following hypotheses:

*H7: The higher the spatial abilities, the higher the perceived behavioral control.*

*H8: The higher the spatial abilities, the lower the intention to use an IPS in a hospital.*

For employees, we investigate their spatial abilities both for buildings that they know (the hospital where they work) and for large unfamiliar buildings, leading to the following hypotheses:

*H9: The higher the spatial abilities for known buildings, the higher the perceived behavioral control.*

*H10: The higher the spatial abilities for large unknown buildings, the higher the perceived behavioral control.*

*H11: The higher the spatial abilities for known buildings, the lower the intention to use an IPS in a hospital.*

*H12: The higher the spatial abilities for unknown buildings, the lower the intention to use an IPS in a hospital.*

The research model developed from these hypotheses is shown in Figure 12.

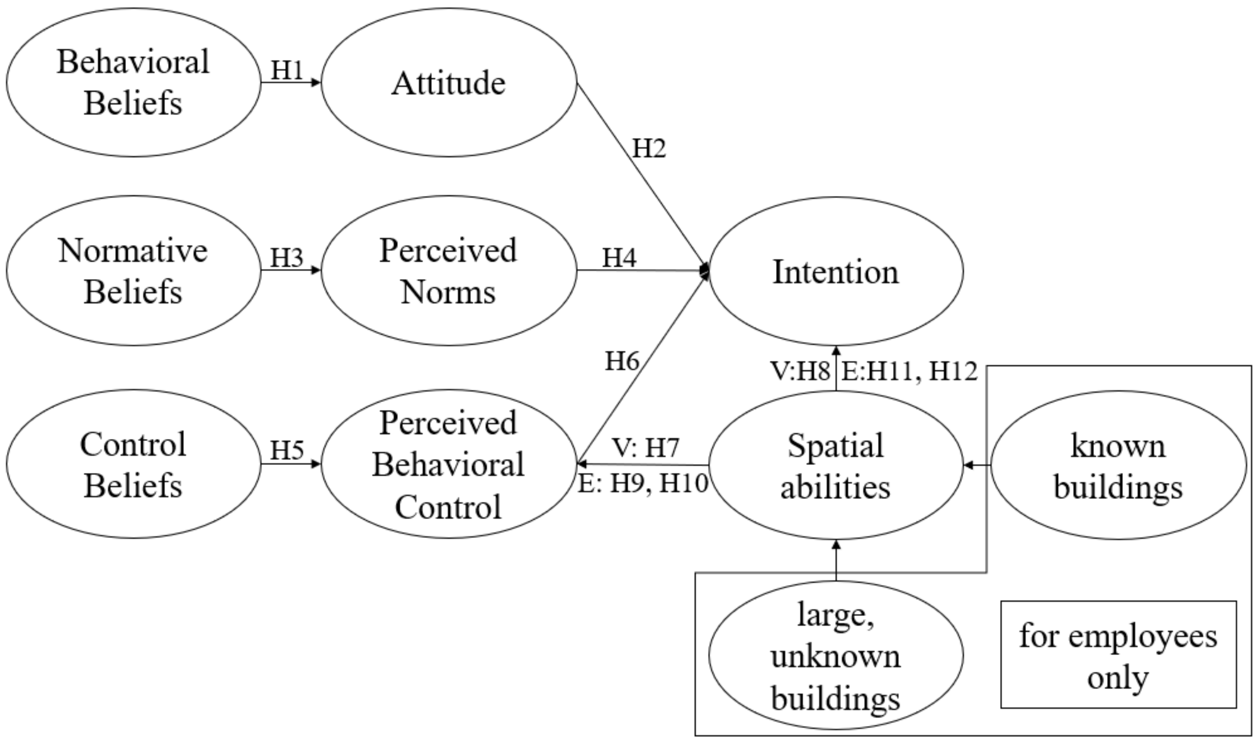


*Figure 12: Research model.*

## 2.4 Methods

### 2.4.1 Measures

We used a 7-point Likert scale for each item (from 1 "do not agree at all" to 7 "completely agree"). As Fishbein and Ajzen [22] noted, "it is important to realize that there is no single reasoned action questionnaire. Each investigation requires the construction of a suitable questionnaire." We, therefore, adjusted the original framework for RAA research to suit the context of IPS in hospitals, creating items that cover relevant behavioral beliefs about time savings and hygiene considerations. In terms of normative beliefs, it is necessary to differentiate between hospital visitors and hospital employees. For visitors, the most relevant normative reference groups are derived from private life, namely family and close friends. For employees, colleagues in the same functional area, colleagues in related functional areas, and superiors are defined as relevant normative groups. In terms of control beliefs, we include ease of access and the necessity of explaining how the IPS functions. We included several control variables (ie, the size of the hospital and types of buildings, the employees' work area, how long employees have been working at the hospital, when visitors or patients were present in the hospital, levels of personal innovativeness, and demographic data such as age and gender). The complete questionnaires can be found in section 2.7.1.

### 2.4.2 Participants and Data Collection

The crowdworking platform Clickworker (similar to Amazon MTurk) was used to gather hospital visitors and employees in Germany in April and August 2020. The questionnaires for visitors and employees were separate. We included test questions at the beginning and end of the questionnaire to ensure that the self-reported status was correct. At the beginning of the process, participants also received a text that explained the main function of an IPS. Since the unsupervised online platform paid the participants for their responses, we followed the recommendations of Goodman et al [24] by keeping the questionnaire short and enriching it with attention checks. Among the hospital visitors, the youngest participant was 18 years of age, and the oldest was 68 years. The mean age was 36.08 years (SD 11.73), with a variance of 137.48 years. A majority (250/323, 77.4%) were aged between 18 and 44 years, and 22.29% (72/323) were between 45 and 64 years. For the hospital employees, the mean age was 33.67 years (SD 9.62), with a variance of 92.37 years. We asked the employees to state the main functional area in which they work. The most common area was nursing care (96/304, 31.58%), followed by hospital management (51/304, 16.78%), building services (37/304, 12.17%), diagnosis and therapy (26/304, 8.55%), research, teaching, and training (20/304, 6.58%), emergency medical services (19/304, 6.25%), pastoral care and social services (16/304, 5.26%), supply and waste management (12/304, 3.95%), integrated ambulant care (12/304, 3.95%), kindergarten for employees (11/304, 3.62%), hospice care (3/304, 0.97%), and patient accommodation (1/304, 0.33%).

### 2.4.3 Validity and Reliability

A partial least squares approach to SEM was used to test the proposed models for hospital visitors and employees. Variance-based SEM is more suitable than covariance-based SEM in cases where the aim is to explain and predict the target construction in structural models or to identify key drivers [25]. Multiple regression analysis, an example of variance-based SEM, develops parameters that “maximize the explained variance of dependent constructs” [25]. We used SmartPLS (version 3.3.3; SmartPLS GmbH) to evaluate our models, estimating our weightings with a path method and determining the significance of the path coefficients using bootstrapping procedures with 5000 samples [25]. We followed the requirements of Hair et al [25] and Hulland [33] by testing (1) internal consistency reliability, (2) indicator reliability, (3) convergent validity, and (4) discriminant validity.

First, composite reliability, used to examine internal consistency, was confirmed for both visitors and employees (section 2.7.5). Second, we investigated the reliability of the indicators concerning the reflective variables “attitude,” “perceived norms,” and “perceived behavioral control” and found the requirements to be fulfilled for both groups (section 2.7.2). Third, convergent validity in terms of the reflective variables was confirmed for both groups (section 2.7.5). Fourth, the discriminant validity of our measures was investigated using heterotrait-monotrait ratios and confirmed for both groups (section 2.7.6). Thus, we conclude that the reliability and validity of the reflective measures are adequate.

The variance inflation factor was used to check for multicollinearity among the indicators for formative belief variables. For both groups, the values were in line with requirements (section 2.7.3). The outer weights and loadings used to test the relative and absolute importance of indicators were all significant for both groups (section 2.7.4). To check heterogeneity between the indicators, we determined whether the bivariate correlations were higher between an indicator and the variable than between the indicators [10]. Investigation of the results identified no suppressors and no collinear indicators for either group. We also conducted several tests to ascertain the quality of our structural model. We used the standardized root mean square residual (SRMR) to determine the approximate fit for our composite factor and common factor models [30]. We obtained .075 for the SRMR composite factor model for the visitors and .10 for the SRMR common factor model. For the employees, the values were .55 and .085, respectively. To evaluate the prediction relevance of the models [31], we followed the literature in using blindfolding procedures with an omission distance of 7 [40]. Both tests yielded positive Stone–Geisser Q2 values (section 2.7.7), allowing us to conclude that the models have strong overall predictive power [31].

## 2.5 Results

The descriptive statistics and correlations for both our samples are given in Table 1. Note that variable 7 applies to visitors and variables 8 and 9 to employees only.

*Table 1: Descriptive statistics for the overall sample and correlations among variables for visitors (V) and employees (E).*

| Variable | Mean (SD) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | V[a]: 33.04 (11.2)<br>E[b]: 29.94 (11.63) | – | V: .51$^{***}$<br>E: .70$^{**}$ | V: .67$^{***}$<br>E: .71$^{**}$ | V: .77$^{***}$<br>E: .74$^{**}$ | V: .53$^{***}$<br>E: .63$^{**}$ | V: .38$^{***}$<br>E: .51$^{**}$ | V: –.21$^{***}$ | E: –.04 | E: .20$^{**}$ | V: .70$^{***}$<br>E: .70$^{**}$ |
| 2 | V: 23.75 (10.44)<br>E: 27.35 (10.34) | | – | V: .52$^{***}$<br>E: .688$^{**}$ | V: .56$^{***}$<br>E: .63$^{**}$ | V: .79$^{***}$<br>E: .74$^{**}$ | V: .21$^{***}$<br>E: .54$^{**}$ | V: .03 | E: .01 | E: .21$^{**}$ | V: .49$^{***}$<br>E: .62$^{**}$ |
| 3 | V: 30.24 (11.27)<br>E: 29.92 (11.84) | | | – | V: .67$^{***}$<br>E: .67$^{**}$ | V: .58$^{***}$<br>E: .65$^{**}$ | V: .28$^{***}$<br>E: .50$^{**}$ | V: –.15$^{**}$ | E: –.08 | E: .19$^{**}$ | V: .71$^{***}$<br>E: .70$^{**}$ |
| 4 | V: 5.55 (1.13)<br>E: 5.39 (1.14) | | | | – | V: .59$^{***}$<br>E: .66$^{**}$ | V: .36$^{***}$<br>E: .43$^{**}$ | V: –.16$^{**}$ | E: .05 | E: .11$^{**}$ | V: .74$^{***}$<br>E: .65$^{**}$ |
| 5 | V: 4.64 (1.30)<br>E: 4.84 (1.23) | | | | | – | V: .15$^{**}$<br>E: .39$^{**}$ | V: –.09 | E: .09 | E: .07 | V: .59$^{***}$<br>E: .66$^{**}$ |
| 6 | V: 6.04 (0.94)<br>E: 5.39 (1.24) | | | | | | – | V: .10 | E: .03 | E: .24$^{**}$ | V: .31$^{***}$<br>E: .48$^{**}$ |
| 7 | V: 4.26 (1.25) | | | | | | | – | – | – | V: –.19$^{**}$ |
| 8 | E: 4.05 (1.50) | | | | | | | | – | E: .43$^{**}$ | E: –.10 |
| 9 | E: 5.30 (1.08) | | | | | | | | | – | E: .04 |
| 10 | V: 5.34 (1.54)<br>E: 5.24 (1.47) | | | | | | | | | | – |

[a]V: n=323; E: n=304.

[b]Number assignment: 1=behavioral beliefs; 2=normative beliefs; 3=control beliefs; 4=attitude; 5=perceived norms; 6=perceived behavioral control; 7=spatial ability; 8=spatial ability large, unknown buildings; 9=spatial ability known buildings; 10=intention.

**P*<.05; ***P*<.01; ****P*<.001; one-tailed tests

The results of our analysis concerning the hospital visitors are presented in Figure 13.

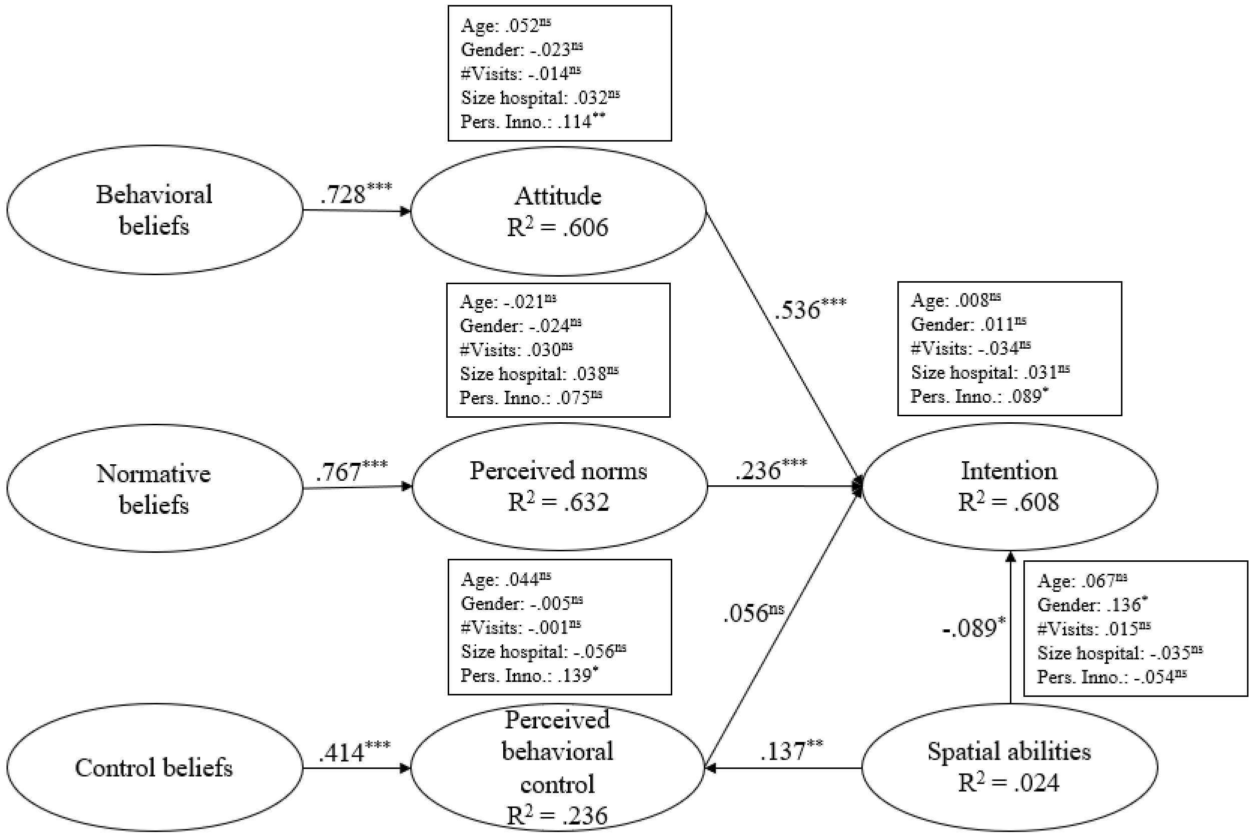


*Figure 13: Research model results for hospital visitors.*
**P<.05; **P<.01; ***P<.001; ns: not significant.*

For the visitors, strong empirical evidence was found in support of H1 (β=.728; P<.001; $f^2$=1.153), H3 (β=.767; P<.001; $f^2$=1.389), and H5 (β=.414; P<.001; $f^2$=0.179), which indicates that the respective beliefs are relevant antecedents. Furthermore, an increase in R2 concerning behavioral beliefs resulted in a higher positive attitude, and 60.6% of the variance can be explained by the behavioral beliefs. Regarding the normative beliefs, the explainable variance in perceived norms is similarly strong (63.2%). In contrast, the variance explained by the control beliefs toward perceived behavioral control is comparatively low (23.6%).

Our investigation of H2 (β=.536; P<.001; $f^2$=.381), H4 (β=.236; P<.001; $f^2$=.087), and H8 (β=–.089; P=.015; $f^2$=.019) supported H2 and H4 but not H8. We determined that attitude has a strong influence on intention to use an IPS in a hospital and that perceived norms (as assessments of the intentions of family and close friends) also have an influence. When we consider navigational skills, it is conspicuous that H8 yields a negative value, suggesting that an increase in spatial abilities leads to a lower intention to use IPS in a hospital. We found that perceived behavioral control is not a predictor of intention to use an IPS (β=.056; P=.129; $f^2$=.006). H6 is therefore not supported. In contrast, H7 is supported, as spatial abilities are a predictor of perceived behavioral control (β=.137; P<.001; $f^2$=.023). We used control variables to verify the research model further and found that they had no significant influence, with the exception of personal innovativeness on attitude (β=.114; P=.001; $f^2$=0.029) and on perceived behavioral control (β=.139; P=.013; $f^2$=0.020). The results of the research model regarding hospital employees are summarized in Figure 14.

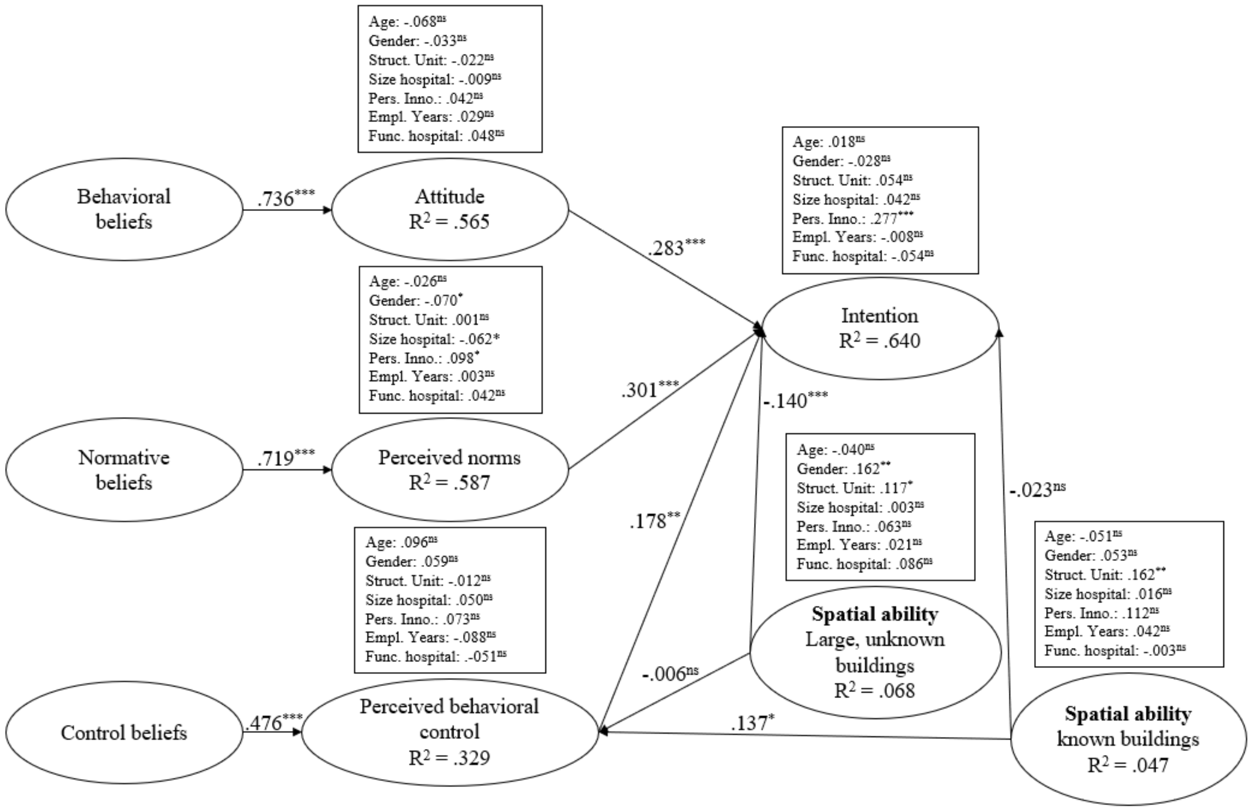


*Figure 14: Research model results for hospital employees.*
**P<.05; **P<.01; ***P<.001; ns: not significant.*

We found strong empirical evidence for H1 (β=.736; P<.001; $f^2$=1.038), H3 (β=.719; P<.001; $f^2$=0.999), and H5 (β=.476; P<.001; $f^2$=0.244), which again indicates that these beliefs are relevant antecedents. The $R^2$ results were similar to those for the visitors' model, in that the behavioral and normative beliefs have a strong influence on attitude (56.5%) and perceived norms (58.7%). The influence of the control beliefs on perceived behavioral control (32.9%) is higher than in the visitors' model.

The results support H2 (β=.283; P<.001; $f^2$=0.114), H4 (β=.301; P<.001; $f^2$=0.126), H6 (β=.178; P<.001; $f^2$=0.062), H11 (β=–.023; P=.310; $f^2$=0.001), and H12 (β=–.140; P<.001; $f^2$=0.041), although the results for H11 are not significant. Thus, all the reflective variables of the RAA (attitude, perceived norms, and perceived behavioral control) are significant for intention to use. Moreover, in line with H12, positive spatial abilities concerning large unknown buildings negatively influence intention to use. Investigation of H9 (β=.137; P=.014; $f^2$=0.001) and H10 (β=–.006; P=.460; $f^2$=0.000) showed that the correlations are not significant. We also established that our control variables, with the exception of gender, had no significant influence on spatial abilities for large unknown buildings (β=.162; P=.003; $f^2$=0.027), personal innovativeness on intention to use (β=.277; P<.001; $f^2$=0.168), and the structural unit in which the employees are employed on spatial abilities for known buildings (β=.162; P=.006; $f^2$=0.023).

As gender and age are important factors in spatial ability [26, 38, 47, 67, 68, 71] and personal innovativeness [48, 61], we post hoc analyzed our data accordingly. We divided the data set into subgroups for women (visitors: n=109; employees: n=124) and men (visitors: n=211; employees: n=178), for ages 18-33 years (n=162) and 34-68 years (n=161) for visitors (combining both genders), and for ages 18-32 years (n=152) and 33-63 years (n=152) for employees. Table 2 gives the significances for the respective groups.

*Table 2: Post hoc analysis by gender and age.*

| No. | Group | Gender | Age, years | Correlation/($f^2$) | β | *P* value |
|---|---|---|---|---|---|---|
| 1 | Visitors | Women | all | SA[a]>PBC[b]/(0.025) | .226 | .008 |
| 2 | Visitors | Men | all | SA>PBC | .061 | .188 |
| 3 | Visitors | Both | 34–68 | SA>PBC | .216 | .001 |
| 4 | Visitors | Both | 18–33 | SA>PBC | .058 | .235 |
| 5 | Visitors | Women | 34–68 | SA>PBC | .300 | .018 |
| 6 | Visitors | Women | 18–33 | SA>PBC | .172 | .098 |
| 7 | Visitors | Men | 34–68 | SA>PBC | .133 | .078 |
| 8 | Visitors | Men | 18–33 | SA>PBC | –.034 | .371 |
| 9 | Employees | Women | all | SA/KB[c]>PBC/(0.020) | .109 | .162 |
| 10 | Employees | Men | all | SA/KB>PBC | .172 | .018 |
| 11 | Employees | Both | 33–63 | SA/KB>PBC | .071 | .232 |
| 12 | Employees | Both | 18–32 | SA/KB>PBC | .177 | .025 |
| 13 | Employees | Women | 33–63 | SA/KB>PBC | .245 | .042 |
| 14 | Employees | Women | 18–32 | SA/KB>PBC | .353 | .002 |
| 15 | Employees | Men | 33–63 | SA/KB>PBC | .169 | .046 |
| 16 | Employees | Men | 18–32 | SA/KB>PBC | .141 | .138 |
| 17 | Employees | Women | all | SA/LUB[d]>I[e]/(0.041) | –.154 | .008 |
| 18 | Employees | Men | all | SA/LUB>I | –.104 | .026 |
| 19 | Employees | Both | 33–63 | SA/LUB>I | –.212 | .000 |
| 20 | Employees | Both | 18–32 | SA/LUB>I | –.076 | .086 |
| 21 | Employees | Women | 33–63 | SA/LUB>I | –.078 | .161 |
| 22 | Employees | Women | 18–32 | SA/LUB>I | –.044 | .299 |
| 23 | Employees | Men | 33–63 | SA/LUB>I | –.161 | .019 |
| 24 | Employees | Men | 18–32 | SA/LUB>I | –.009 | .453 |
| 25 | Visitors | Women | all | PI[f]>Att[g]/(0.024) | .094 | .072 |
| 26 | Visitors | Men | all | PI>Att | .113 | .011 |
| 27 | Visitors | both | 34–68 | PI>Att | .027 | .285 |
| 28 | Visitors | both | 18–33 | PI>Att | .200 | .000 |
| 29 | Visitors | Women | 34–68 | PI>Att | –.060 | .239 |
| 30 | Visitors | Women | 18–33 | PI>Att | .223 | .006 |
| 31 | Visitors | Men | 34–68 | PI>Att | .087 | .103 |
| 32 | Visitors | Men | 18–33 | PI>Att | .119 | .043 |
| 33 | Visitors | Women | all | PI>PBC | .189 | .047 |
| 34 | Visitors | Men | all | PI>PBC | .119 | .045 |
| 35 | Visitors | both | 34–68 | PI>PBC | .175 | .018 |
| 36 | Visitors | both | 18–33 | PI>PBC | .100 | .138 |

| No. | Group | Gender | Age, years | Correlation/($f^2$) | β | *P* value |
|---|---|---|---|---|---|---|
| 37 | Visitors | Women | 34–68 | PI>PBC | .237 | .090 |
| 38 | Visitors | Women | 18–33 | PI>PBC | .181 | .153 |
| 39 | Visitors | Men | 34–68 | PI>PBC | .163 | .052 |
| 40 | Visitors | Men | 18–33 | PI>PBC | .047 | .337 |
| 41 | Employees | Women | all | PI>I/(0.168) | .248 | .001 |
| 42 | Employees | Men | all | PI>I | .319 | .000 |
| 43 | Employees | both | 33–63 | PI>I | .243 | .000 |
| 44 | Employees | both | 18–32 | PI>I | .315 | .000 |
| 45 | Employees | Women | 33–63 | PI>I | .186 | .040 |
| 46 | Employees | Women | 18–32 | PI>I | .201 | .039 |
| 47 | Employees | Men | 33–63 | PI>I | .238 | .003 |
| 48 | Employees | Men | 18–32 | PI>I | .440 | .000 |

[a]SA: spatial ability.
[b]PBC: perceived behavioral control.
[c]KB: known buildings.
[d]LUB: large unknown buildings.
[e]I: intention.
[f]PI: personal innovativeness.
[g]Att: attitude.

## 2.6 Discussion

### 2.6.1 Principal Findings

In our investigation of intention to use an IPS in a hospital, we identified significant differences between visitors and employees. First, while perceived behavioral control is not significant in determining visitors' intention to use (β=–.056; P=.129; $f^2$=0.016), it is significant for employees (β=.178; P=.005; $f^2$=0.062). Thus, active control over the intention to use an IPS is more relevant for employees than visitors. This might reflect the fact that employees are more experienced than visitors in finding their way around a hospital. Other studies concerning navigational [66] and health care–related [43, 63] occupational contexts seem to support this theory.

Second, spatial abilities are significant for perceived behavioral control regarding hospital visitors (β=.137; P=.006; $f^2$=0.023) and known buildings (β=.137; P=.014; $f^2$=0.020). However, they are not significant for large unknown buildings from the viewpoint of hospital employees (β=–.006; P=.460; $f^2$=0.000). Thus, the urgency of using an IPS in a building known to the employee (eg, the hospital where she or he is employed) is lower if the employee's spatial abilities are high, but this is not the case for large unknown buildings. Likewise, spatial abilities are not a predictor of visitors' intention to use an IPS (β=–.089; P=.015; $f^2$=0.016) or the spatial abilities of employees with regards to known buildings (β=–.023; P=.310; $f^2$=0.001). In contrast, spatial abilities are a predictor for employees using an IPS with respect to large unknown buildings (β=–.140; P<.001; $f^2$=0.041), which indicates that employees have an intention to use an IPS if the building is large and unfamiliar.

For visitors, personal innovativeness is not significant for intention to use an IPS ($\beta$=.089; P=.022; $f^2$=0.016); however, it is significant for employees ($\beta$=.277; P<.001; $f^2$=0.168). This insight aligns with previous research, as personal innovativeness is an important predictor of behavioral intention [67, 68].

In current research on spatial abilities, the influence of gender is disputed; research that uses abstract measures, such as mental rotation, indicates that men are better than women at wayfinding [26, 47], while research in indoor contexts has identified no major gender differences [43, 63]). In this study, for hospital visitors, we found that the older age group (those aged 34-68 years), and especially women, tend to be more realistic about their spatial abilities and their need to use an IPS (see Table 2, numbers 1-8). This suggests that women have greater feelings of uncertainty about wayfinding in a building. However, although women are more likely to use navigation systems [66], actual wayfinding performance does not differ by gender [42].

The findings concerning the impact of the spatial abilities of employees for known buildings on perceived behavioral control align with the findings for visitors. However, it should be noted that the path is also significant for male employees aged 33-63 years (see Table 2, numbers 9-16). These results support the view that physical age and improved experience are positively related, as navigational experience initially increases with age [66], before decreasing in elderly people (an age group not represented in this study) [38, 71]. The results in relation to large unknown buildings show that, for both genders and all the age groups under study, higher spatial abilities lead to lower intention to use an IPS in a hospital. However, there is some discrepancy in the results for the different age groups, with a significance for men aged 33-63 years (see Table 2, numbers 17-24), which we ascribe to experience in navigation [66].

For unfamiliar environments, other aspects may be more relevant in determining the urgency of navigational assistance and thus intention to use an IPS, such as the complexity of the environment [45]. In terms of the influence of personal innovativeness on the attitude of hospital visitors, we determined that the path is significant for men and for younger individuals (those aged 18-33 years; see Table 2, numbers 25-32). Concerning personal innovativeness and perceived behavioral control, the path is mainly driven by older participants and is independent of gender (see Table 2, numbers 33-40).

Hence, our results support the consensus in technology adoption research that there is a gender difference. Men's decisions to adopt new technology are driven mainly by their attitude toward the technology, whereas women's decisions are driven by subjective norms and perceived behavioral control [61]. Concerning the influence of personal innovativeness on attitude and perceived behavioral control, research has determined that attitude toward new technology is more relevant for younger workers, whereas perceived norms and perceived behavioral control are more relevant for older workers [61]. Our findings support these insights by identifying a positive influence of personal innovativeness on intention to use for all genders and age groups (see Table 2, numbers 41-48). An IPS is aimed at individuals who like to explore and experiment with new information technologies, which is a common perception in research on information system adoption and use [27, 44].

To clarify the influence of the employees' structural unit on their spatial abilities for known buildings, we post hoc analyzed our data set according to the functional areas in which the individuals are employed. Thus, we distinguished between employees who move through hospital buildings frequently because of their occupation (ie, those in nursing care, building services, and emergency medical services) and those who work mainly in the same place (all the other functional areas represented in our data; see section 2.4.2). We found that employees who work mainly in the same place are more confident in their spatial abilities in relation to known buildings (β=.194; P=.017, $f^2$=0.023) than those participants frequently moving (β=.088; P=.172), which we ascribe to the fact that those employees who work mainly in the same place have a lower range of motion in the hospital and have to know a fewer number of floors or buildings, respectively.

Concerning the core model of the RAA, our investigation indicates that attitude and perceived norms are strong predictors of intention to use an IPS in a hospital. For hospital employees, the results are more differentiated; all the reflective variables of the RAA (attitude, perceived norms, and perceived behavioral control) are significant for intention to use, with perceived norms having the strongest influence. Attitude driven by behavioral beliefs is a major predictor of intention to use [22]. Our model indicates that this is the case for hospital visitors and confirms that it is important for hospital employees. In terms of perceived norms, rational choice theorists argue that individual behavior is usually conducted in accordance with self-interest and that we, therefore, accept social norms as limits on those behaviors. In this article, we ensure that social norms do not represent an individual's interest only but that of a larger social system [9]. We established that perceived norms significantly influence intention to use the system for both hospital visitors (with family and close friends as the reference groups) and hospital employees. Moreover, perceived norms are the most important predictors for employees, reflecting the importance of recommendations from immediate colleagues and colleagues working in other functional areas and superiors.

The descriptive statistics for spatial abilities show a mean of 4.18 (SD 1.56) for visitors, and for employers, a mean of 4.05 (SD 1.69) for large unknown buildings and a mean of 5.29 (SD 1.34) for known buildings. These results indicate that employees tend to navigate better through known buildings than through large unknown buildings, although no such tendency is found for visitors. For the influence of the personal innovativeness of employees on their intention to use an IPS, the mean value of 4.86 (SD 1.54) suggests that employees intend to use an IPS if they are personally innovative in terms of new technologies (see section 2.7.1). The mean values for all three intention items (on a scale of 1 to 7; visitors: n=323 and employees: n=304) are as follows: intention 1 (visitors: mean 5.35, SD 1.60; employees: mean 5.36, SD 1.53); intention 2 (visitors: mean 5.39, SD 1.57; employees: mean 5.23, SD 1.58); intention 3 (visitors: mean 5.27, SD 1.61; employees: mean 5.15, SD 1.57). Thus, our model indicates that both visitors and employees have a positive intention to use an IPS. Accordingly, we recommend that hospitals pursue IPS implementation.

### 2.6.2 Conclusion

We analyzed the relevance of IPS in hospitals by considering the perspectives of the main actors, visitors, and employees. The explained variance indicates that intention to use is well predicted and that relevant aspects in the context are covered. This confirms that RAA is an appropriate approach for determining intention to use an IPS in a hospital. Furthermore, our results show that individual attitude and the social norms of relevant reference groups positively impact intention to use an IPS in a hospital. For employees, perceived behavioral control also positively influences intention to use an IPS. These results have many implications for theory, practice, and future research.

#### *2.6.2.1 Theoretical Implications*

Our study design and findings contribute to the literature in several ways. First, we add to the knowledge of how systems or applications, specifically IPS, in the health care management context are accepted by actors in a hospital. Whereas related work regarding general health care tracking apps, including COVID-19-

related apps [49], has focused on general use with a broad public interest, we provide insights into a spatially limited organizational context. Second, we integrate two major stakeholder groups into our analysis: general users, such as patients or visitors, and professional staff. As such, we demonstrate how health care management applications are perceived from a nonexpert perspective, thereby building on previous research, which has generally adopted an expert perspective [65].

Third, we introduce the RAA to analyze intention to use applications in the health care management context, thereby extending the theory conceptually and empirically into a context that considers spatial abilities and personal innovativeness. The high explained variance confirms that the theory is helpful for understanding the reasons for adoption intentions. This increased focus on analyzing the influence of different beliefs from a functional perspective extends other theories that have been applied in the context, such as uncertainty reduction theory [49] and protection motivation theory [37].

Fourth, our extension of the RAA to cover spatial abilities and personal innovativeness contributes to the understanding of gender-related and age-related spatial ability. Hence, we demonstrate that demographics matter and should be considered when analyzing the acceptance of applications in a health care management context.

#### *2.6.2.2 Practical Implications*

From a practical perspective, we recommend that hospitals invest in implementing IPS, as our results show that the potential user intention is high. Furthermore, IPS market research forecasts indicate that low-energy Bluetooth will be one of the most lucrative segments of the IPS market [41], thanks to the low hardware costs and low energy consumption [58]. These forecasts lend support to our recommendation.

However, the IPS design requirements of hospital visitors and employees are different. From our finding that visitors' attitudes and perceived norms are the most important predictors of their intention to use, it follows that the system needs to be simple and self-explanatory. The main focus of the application should be navigation to specific rooms or points of interest. If those services function properly, visitors are likely to recommend the system to reference groups that are important to them (eg, close friends and family), who will then assess and use the system accordingly.

For hospital employees, attitude and perceived norms are also relevant. However, the system needs a different functional focus for employees, whose intentions are determined by perceived behavioral control. Our research model shows that employees that work mainly in the same place are confident in their spatial abilities for known buildings. In other words, they do not need navigational services for specific rooms or points of interest in the hospital building in which they are employed. Asset tracking, in contrast, is more relevant, as this can facilitate daily work and help reduce redundant activity.

#### *2.6.2.3 Limitations and Future Research*

Our study is subject to some limitations that inform future research. First, we used the crowdworking platform Clickworker to gather our participants. This decision partly predetermined the personal innovativeness of our respondents, as individuals who use digital platforms are likely to be more personally innovative than those who respond to a pen and paper survey. Second, our study design involves convenience sampling, albeit with specific criteria for participation. Thus, we cannot claim that our sample is representative, and further research should focus on a defined target population. Third, our participants are from a single country, Germany. Future studies should cover different countries to identify additional relevant factors. Fourth, our research does not consider other settings, such as large hardware stores, that may be relevant to and interact with the hospital context. Therefore, future research should investigate general acceptance of IPS by, for example, determining the likelihood of using an IPS in a hardware store after using it in a hospital.

## 2.7 Appendix

### 2.7.1 Questionnaire

As two different surveys were conducted, two different questionnaires exist. Therefore, the statements following "B" belong to both questionnaires, whereas arguments containing "V" represent hospital visitors and "E" representing the hospital employees.

| |
|---|
| B: .5 – control question – size of the hospital |
| B: Which building structure has the hospital that you have visited most frequently in the past 365 days? |
| B: -1- hospital with the structure of an office building |
| B: -2- hospital with the structure of a skyscraper |
| B: -3- hospital that is distributed over several buildings |
| B: -4- hospital that is distributed over a large area |
| E: 0.75 – control question – functional area in the hospital |
| E: Which of the following functional areas is the one you are mostly working in? |
| E: -1- Diagnosis and Therapy |
| E: -2- Nursing Care |
| E: -3- Nursing Home Management |
| E: -4- Hospital Management |
| E: -5- Supply- and Waste Management |
| E: -6- Research, Teaching and Training |
| E: -7- Pastoral Care and Social Services |
| E: -8- Emergency Medical Service |
| E: -9- Kindergarten for Employees |
| E: -10- Patient Hotel |
| E: -11- Medical Advisory Service of the Statutory Health Insurance Funds |
| E: -12- Hospice |
| E: -13- Integrated Ambulant Care |
| E: -14- Building Services |
| B: 1 – behavioral beliefs |
| E: -1- An application for indoor navigation would help me to get the information needed to find devices that I need to conduct my work. |
| E: -2- It is important to me to get the information needed to find devices that I need to conduct my work. |

| |
|---|
| B: -(V:1)(E:3)- An application for indoor navigation would help me move hygienically along the shortest routes in the hospital. |
| B: -(V:2)(E:4)- It is important to me to move as hygienic as possible through the hospital. |
| B: -(V:3)(E:5)- An application for indoor navigation would be an appropriate solution to help me find my destination. |
| B: -(V:4)(E:6)- The ease of use of applications for indoor navigation is very important to me. |
| B: 2 – attitude |
| B: The use of an application for indoor navigation would be… |
| B: -1- … advantageous. |
| B: -2- … satisfactory. |
| B: -3- … important. |
| B: -4- … enjoyable. |
| B: -5- I would like the use of an application for indoor navigation. |
| B: 3 – normative beliefs |
| V: -1- My family would advise me to use applications for indoor navigation. |
| V: -2- I generally take my family's advice very seriously. |
| V: -3- My best friends would advise me to use applications for indoor navigation. |
| V: -4- I generally take my best friends' advice very seriously. |
| E: -1- My colleagues in other functional areas in the hospital would advise me to use applications for indoor navigation. |
| E: -2- I generally take some advice from colleagues in other functional areas in the hospital very seriously. |
| E: -3- My colleagues in the same functional area in the hospital would advise me to use applications for indoor navigation. |
| E: -4- I generally take some advice from colleagues in the same functional area in the hospital very seriously. |
| E: -5- My superior would advise me to use applications for indoor navigation. |
| E: -6- I generally take some advice from my superior very seriously. |
| B: 4 – perceived norms |
| B: -1- Individuals from whom I let myself be influenced would advise me to use applications for indoor navigation. |
| B: -2- Individuals who are important to me would advise me to use applications for indoor navigation. |
| B: -3- Individuals whose opinion I appreciate would advise me to use applications for indoor navigation. |
| B: -4- Individuals in a situation comparable to myself would advise me to use applications for indoor navigation. |
| B: 5 – control beliefs |
| B: -1- I would use this application for indoor navigation because it would be easily accessible to me. |
| B: -2- The easy accessibility to applications for indoor navigation is very important to me. |
| B: -3- I would use this application for indoor navigation as far as I get the application explained accordingly. |
| B: -4- The explanation of the use of an application for indoor navigation is very important to me. |

| |
|---|
| B: 6 – perceived behavioral control |
| B: -1- It is under my control to use applications for indoor navigation. |
| B: -2- It is mainly up to me to use applications for indoor navigation. |
| B: -3- I am convinced that I can use applications for indoor navigation. |
| B: -4- If I really want to, I can use applications for indoor navigation. |
| B: 7 – intention |
| B: -1- I would definitely use such an application for indoor navigation during my next visit to a hospital if it would be available. Mean Value: V: 5.35; E: 5.36, Standard Deviation: V: 1.60; E: 1.53 |
| B: -2- I intend to use such an application for indoor navigation during my next visit to a hospital if it would be available. Mean Value: V: 5.39; E: 5.23, Standard Deviation: V: 1.57; E: 1.58 |
| B: -3- I plan to use such an application for indoor navigation during my next visit to a hospital if it would be available. Mean Value: V: 5.27; E: 5.15, Standard Deviation: V: 1.61; E: 1.57 |
| B: 8 – spatial abilities |
| V: -1- I am good in navigating myself through buildings. Mean Value: 4.64, Standard Deviation: 1.51 |
| V: -2- I always find the shortest way through buildings while I am navigating myself. Mean Value: 3.95, Standard Deviation: 1.61 |
| V: -3- I do not need assistance while navigating myself through buildings. Mean Value: 3.95, Standard Deviation: 1.60 |
| E: -1- I am good in navigating myself through buildings that are large and unknown to me. Mean Value: 4.37, Standard Deviation: 1.61 |
| E: -2- I am good in navigating myself through buildings that are known to me. Mean Value: 5.49, Standard Deviation: 1.27 |
| E: -3- I always find the shortest way through buildings that are large and unknown to me, while I am navigating myself. Mean Value: 3.90, Standard Deviation: 1.76 |
| E: -4- I always find the shortest way through buildings that are known to me, while I am navigating myself. Mean Value: 5.19, Standard Deviation: 1.29 |
| E: -5- I do not need assistance while navigating myself through buildings, that are large and unknown to me. Mean Value: 3.89, Standard Deviation: 1.70 |
| E: -6- I do not need assistance while navigating myself trough buildings, that are known to me. Mean Value: 5.21, Standard Deviation: 1.45 |
| B: 9 – personal innovativeness |
| B: -1- When I hear about new information technology, I look forward to experimenting with it. Mean Value: V: 5.36; E: 5.32, Standard Deviation: V: 1.37; E: 1.35 |
| B: -2- I am usually the first of my friends to try new information technology. Mean Value: V: 4.37; E: 4.68, Standard Deviation: V: 1.68; E: 1.61 |
| B: -3- Basically, I am reluctant to try out new information technologies. Mean Value: V: 3.21; E: 4.29, Standard Deviation: V: 1.61; E: 1.76 |
| B: -4- I like to experiment with new information technologies. Mean Value: V: 5.12; E: 5.13, Standard Deviation: V: 1.43; E: 1.45 |

### 2.7.2 Loadings of reflective variables

| Construct | Item | Loadings |
|---|---|---|
| Attitude | The use of an application for indoor navigation would be… | |
| | -1- … advantageous. | V: 0.908<br>E: 0.879 |
| | -2- … satisfactory. | V: 0.852<br>E: 0.789 |
| | -3- … important. | V: 0.833<br>E: 0.774 |
| | -4- … enjoyable. | V: 0.86<br>E: 0.876 |
| | -5- I would like the use of an application for indoor navigation. | V: 0.924<br>E: 0.896 |
| Perceived Norms | -1- Individuals from whom I let myself be influenced would advise me to use applications for indoor navigation. | V: 0.918<br>E: 0.874 |
| | -2- Individuals who are important to me would advise me to use applications for indoor navigation. | V: 0.948<br>E: 0.908 |
| | -3- Individuals whose opinion I appreciate would advise me to use applications for indoor navigation. | V: 0.948<br>E: 0.893 |
| | -4- Individuals in a situation comparable to myself would advise me to use applications for indoor navigation. | V: 0.863<br>E: 0.887 |
| Perceived Behavioral Control | -1- It is under my control to use applications for indoor navigation. | V: 0.761<br>E: 0.807 |
| | -2- It is mainly up to me to use applications for indoor navigation. | V: 0.825<br>E: 0.822 |
| | -3- I am convinced that I can use applications for indoor navigation. | V: 0.849<br>E: 0.847 |
| | -4- If I really want to, I can use applications for indoor navigation. | V: 0.853<br>E: 0.870 |
| Intention | -1- I would definitely use such an application for indoor navigation during my next visit to a hospital if it would be available. | V: 0.954<br>E: 0.936 |
| | -2- I intend to use such an application for indoor navigation during my next visit to a hospital if it would be available. | V: 0.975<br>E: 0.957 |
| | -3- I plan to use such an application for indoor navigation during my next visit to a hospital if it would be available. | V: 0.973<br>E: 0.923 |

### 2.7.3 VIF values

| Item | VIF |
|---|---|
| B: 1 – behavioral beliefs | |
| E: “-1- An application for indoor navigation would help me to get the information needed to find devices that I need to conduct my work.” X E: “-2- It is important to me to get the information needed to find devices that I need to conduct my work.” | E: 2.011 |
| B: “-(V:1)(E:3)- An application for indoor navigation would help me move hygienically along the shortest routes in the hospital.” X B: “-(V:2)(E:4)- It is important to me to move as hygienic as possible through the hospital.” | V: 2.1<br>E: 2.114 |
| B: “-(V:3)(E:5)- An application for indoor navigation would be an appropriate solution to help me find my destination.” X B: “-(V:4)(E:6)- The ease of use of applications for indoor navigation is very important to me.” | V: 2.1<br>E: 2.566 |
| B: 3 – normative beliefs | |
| V: “-1- My family would advise me to use applications for indoor navigation.” X V: “-2- I generally take my family’s advice very seriously.” | V: 1.807 |
| V: “-3- My best friends would advise me to use applications for indoor navigation.” X V: “-4- I generally take my best friends’ advice very seriously.” | V: 1.807 |
| E: “-1- My colleagues in other functional areas in the hospital would advise me to use applications for indoor navigation.” X E: “-2- I generally take some advice from colleagues in other functional areas in the hospital very seriously.” | E: 3.018 |
| E: “-3- My colleagues in the same functional area in the hospital would advise me to use applications for indoor navigation.” X E: “-4- I generally take some advice from colleagues in the same functional area in the hospital very seriously.” | E: 3.046 |
| E: “-5- My superior would advise me to use applications for indoor navigation.” X E: “-6- I generally take some advice from my superior very seriously.” | E: 2.386 |
| B: 5 – control beliefs | |
| B: “-1- I would use this application for indoor navigation because it would be easily accessible to me.” X B: “-2- The easy accessibility to applications for indoor navigation is very important to me.” | V: 1.285<br>E: 1.682 |
| B: “-3- I would use this application for indoor navigation as far as I get the application explained accordingly.” X B: “-4- The explanation of the use of an application for indoor navigation is very important to me.” | V: 1.285<br>E: 1.682 |

### 2.7.4 Loadings and weights of formative variables

| Construct | Item | Loadings | Weights |
|---|---|---|---|
| behavioral beliefs | E: (BB1) | E: 0.850 | E: 0.326 |
| | V: (BB1) / E: (BB2) | V: 0.938 / E: 0.868 | V: 0.574 / E: 0.351 |
| | V: (BB2) / E: (BB3) | V: 0.918 / E: 0.925 | V: 0.503 / E: 0.451 |
| normative beliefs | V: (NB1) / E: (NB1) | V: 0.884 / E: 0.905 | V: 0.463 / E: 0.316 |

| | | | |
|---|---|---|---|
| | V: (NB2) / E: (NB2) | V: 0.939 / E: 0.969 | V: 0.629 / E: 0.617 |
| | E: (NB3) | E: 0.815 | E: 0.142 |
| control beliefs | V: (CB1) / E: (CB1) | V: 0.957 / E: 0.995 | V: 1.111 / E: 0.913 |
| | V: (CB2) / E: (CB2) | V: 0.196 / E: 0.710 | V: -0.327 / E: 0.129 |

### 2.7.5 Composite Reliability and AVE

| | Composite Reliability | Average Variance Extracted (AVE) |
|---|---|---|
| B: attitude | V: 0.943 / E: 0.925 | V: 0.767 / E: 0.713 |
| B: perceived norms | V: 0.956 / E: 0.939 | V: 0.846 / E: 0.793 |
| V: spatial ability | V: 0.906 | V: 0.764 |
| E: spatial ability large, unknown buildings | E: 0.916 | E: 0.784 |
| E: spatial ability known buildings | E: 0.849 | E: 0.655 |
| B: intention | V: 0.978 / E: 0.957 | V: 0.936 / E: 0.882 |
| B: personal innovativeness | V: 0.908 / E: 0.882 | V: 0.714 / E: 0.667 |
| B: perceived behavioral control | V: 0.893 / E: 0.903 | V: 0.677 / E: 0.700 |

### 2.7.6 HTMT values

Note that the variables 2 and 5 apply to visitors and variables 11 to 15 to employees only.

| | B: 1 | *V: 2* | B: 3 | B: 4 | *V: 5* | B: 6 | B: 7 | B: 8 | B: 9 | B: 10 | E: 11 | E: 12 | E: 13 | E: 14 | E: 15 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | | 1 |
| *2* | V: .052 | | | | | | | | | | | | | | | *2* |
| 3 | V: .092 E: .045 | V: .031 | | | | | | | | | | | | | | 3 |
| 4 | V: .028 E: .027 | V: .038 | V: .633 E: .726 | | | | | | | | | | | | | 4 |
| 5 | V: .086 | V: .009 | V: .188 | V: .102 | | | | | | | | | | | | 5 |
| 6 | V: .036 E: | V: .004 | V: .126 E: | V: .115 E: | V: .121 | | | | | | | | | | | 6 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | .006 | | .038 | .034 | | | | | | | | | | | | |
| 7 | V: .055 E: .041 | V: .101 | V: .098 E: .023 | V: .010 E: .054 | V: .028 | V: .120 E: .017 | | | | | | | | | | 7 |
| 8 | V: .034 E: .013 | V: .012 | V: .782 E: .705 | V: .623 E: .710 | V: .213 | V: .073 E: .042 | V: .088 E: .049 | | | | | | | | | 8 |
| 9 | V: .130 E: .072 | V: .020 | V: .310 E: .346 | V: .308 E: .405 | V: .74 | V: .181 E: .103 | V: .092 E: .027 | V: .352 E: .559 | | | | | | | | 9 |
| 10 | V: .043 E: .027 | V: .030 | V: .414 E: .498 | V: .173 E: .448 | V: .080 | V: .028 E: .103 | V: .028 E: .073 | V: .345 E: .548 | V: .332 E: .311 | | | | | | | 10 |
| 11 | E: .068 | | E: .031 | E: .018 | | E: .101 | E: .100 | E: .078 | E: .025 | E: .061 | | | | | | 11 |
| 12 | E: .027 | | E: .072 | E: .114 | | E: .207 | E: .027 | E: .116 | E: .216 | E: .108 | E: .148 | | | | | 12 |
| 13 | E: .051 | | E: .153 | E: .176 | | E: .115 | E: .031 | E: .150 | E: .168 | E: .306 | E: .077 | E: .539 | | | | 13 |
| 14 | E: .124 | | E: .037 | E: .040 | | E: .117 | E: .056 | E: .044 | E: .042 | E: .047 | E: .347 | E: .174 | E: .198 | | | 14 |
| 15 | E: .597 | | E: .041 | E: .043 | | E: .115 | E: .052 | E: .025 | E: .035 | E: .035 | E: .048 | E: .021 | E: .022 | E: .029 | | 15 |

Number assignment

1 = age; 2 = number of visits; 3 = attitude; 4 = perceived norms; 5 = spatial ability; 6 = gender; 7 = hospital size; 8 = intention; 9 = personal innovativeness; 10 = perceived behavioral control; 11 = function hospital; 12 = spatial ability large, unknown buildings; 13 = spatial ability known buildings; 14 = structural unit hospital; 15 = years of employment (in the hospital)

### 2.7.7 Stone-Geisser-values

| | Q² (=1-SSE/SSO) |
|---|---|
| B: attitude | V: 0.457<br>E: 0.387 |
| B: perceived norms | V: 0.527<br>E: 0.453 |
| V: spatial ability | V: 0.012 |
| E: spatial ability large, unknown buildings | E: 0.041 |
| E: spatial ability known buildings | E: 0.014 |

| | |
|---|---|
| B: intention | V: 0.560<br>E: 0.549 |
| B: perceived behavioral control | V: 0.147<br>E: 0.210 |

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# 3 Indoor Positioning Systems in Hospitals: A Scoping Review[5]

*Johannes Wichmann*

**Abstract**

**Background:** Indoor navigation within closed facilities has been subject of studies with different application areas, particularly in recent years (eg, the navigation requirements of people or the location of objects). Hospitals are of specific interest in this regard as the multitude of technical equipment used is potentially interfering with navigation systems.

**Objective:** This research examines relevant studies regarding Indoor Positioning Systems (IPS) in hospitals and IPS that are designed for hospitals and in preparation for implementation, by investigating the respective technologies, techniques, prediction-improving methods, evaluation results, and limitations of the IPS.

**Methods:** To gather current and future IPS in hospitals, the methodology of a Scoping Review was used. The study has been conducted by applying the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Framework to the context of IPS in hospitals. The results and limitations concerning current and future IPS in hospitals were gathered and structured by using a highly cited evaluation framework for IPS.

**Results:** 38 studies were considered for this research. The IPS technologies investigated were Bluetooth Low Energy (n=17), Wireless-Fidelity (n=10), Hybrids (n=4), Radio-Frequency Identification (n=4), Ultra-Wideband (n=1), Infrared (n=1) and ZigBee (n=1).

**Conclusions:** This study presents current and future IPS in hospitals. For future IPS research and IPS in hospitals, the theoretical implications contribute to our knowledge about IPS technologies, techniques, prediction-improving methods, evaluation results and limitations during testing/implementing IPS in hospitals. As practical implications, the insights of this study can be used by developers to improve IPS and by hospitals to facilitate IPS implementation.

[5] The article has been accepted for publication in the DIGITAL HEALTH journal [59].

## 3.1 Introduction

The rapid development of various electronic services, such as Internet of Things [14], over the past decade, has resulted in a multitude of innovations. Two of them are the navigation of individuals and the localization of objects within buildings. The use of those innovations in hospitals is of special importance, especially under consideration of pandemic crises and needs for isolation [11, 24]. Because health measures are highly complex and handled individually [55], it is important to use the already scarce resources efficiently and to avoid redundant activities [18, 45, 55]. Indoor Positioning Systems (IPS) as measures to track people and objects [8] should help to ensure that no resources for redundant activities in this context are raised, eg, finding the right room or important objects, such as respirators. Since hospitals have a unique environment concerning radiation and electromagnetic fields, eg, X-Ray and high frequency fields, those circumstances are especially relevant for IPS in hospitals as they influence the IPS measures [8, 46]. Additionally, they confine the adaptability of challenges of other IPS research (eg, shopping malls), as they do not use medical devices that emit radiation, like eg, X-Ray [8, 46] which underpins the practical relevance of this study. From a theoretical point of view, system implementations in hospitals are known to be costly [1, 41] and the success of an IT intervention depends as much on the implementation as on the system itself [52], which also supports the need for this study. Thereby, the aim of this research is to provide a Scoping Review about (a) objectives of IPS in hospitals; (b) IPS technologies for hospitals; (c) their localization techniques; (d) their prediction-improving methods, and (e) to evaluate the IPS concerning the criteria: (i) accuracy, (ii) availability, (iii) cost, (iv) energy efficiency, (v) latency/delay, (vi) precision, (vii) reception range, (viii) robustness, and (ix) scalability. Then, the insights of this study can be used practically, eg, to determine an appropriate IPS for a hospital as well as theoretically, eg, (a) to facilitate the implementation of an IPS and to keep the costs therefore low as well as; (b) to avoid pitfalls during the development of a new IPS by considering the limitations of the existing and future IPS for hospitals. Consequently, this study is relevant for the following stakeholder groups: (i) researchers who investigate the adoption, diffusion, and evaluation of information technologies (IT) for hospitals, (ii) IT developers for hospitals as well as (iii) hospital management that try to determine an appropriate IPS for their hospital.

Accordingly, this paper is structured as follows: section 3.2 describes the concept of IPS in hospitals. Section 3.3 represents the Scoping Review methodology as well as the search strategy and standardized data extraction form for IPS research in hospitals. Section 3.4 reflects the outcome of this study, presenting technologies, techniques, prediction-improving methods, evaluation results, and limitations of current and future IPS in hospitals. Section 3.5 evaluates the outcomes, while the section 3.6 represents the implications and limitations of this study (for a better understanding, see Figure 17). For additional information concerning the limitations of current and future IPS in hospitals, see the Appendix (section 3.7).

## 3.2 Conceptual Background

For indoor positioning purposes, respective systems are necessary. These systems are dedicated to ascertain a specific position of an asset or individual and/or to track them [9]. Thereby, a localization technique determines the position of a mobile client (eg, the tag attached to the wheelchair in the middle of Figure 15 as well as the tablet on the left-hand side and the wristband on the right-hand side) by utilizing a set of reference points (eg, the routers in Figure 15) within a specific area [12] by using several technologies (eg, Wireless-Fidelity (Wi-Fi) or Bluetooth Low Energy (BLE)). The technique (such as triangulation that is illustrated by the three circles next to the right router in Figure 15 or trilateration as represented by the triangle in Figure 1 below the left router) utilizes (a) specific signal(s) of the respective technology (such as the Received Signal Strength Indication (RSSI)) [22]. If desired, prediction-improving methods can be used to improve the performance of the IPS, eg, by using filters [37]. In accordance to the implementation of the system, it can be used to support several tasks in a hospital, such as to track insulin pumps [56], to track patients in the emergency department [25] or to reduce waiting times and redundant activities. For a better understanding, Figure 15 represents an exemplary functional setup for an IPS in a hospital.

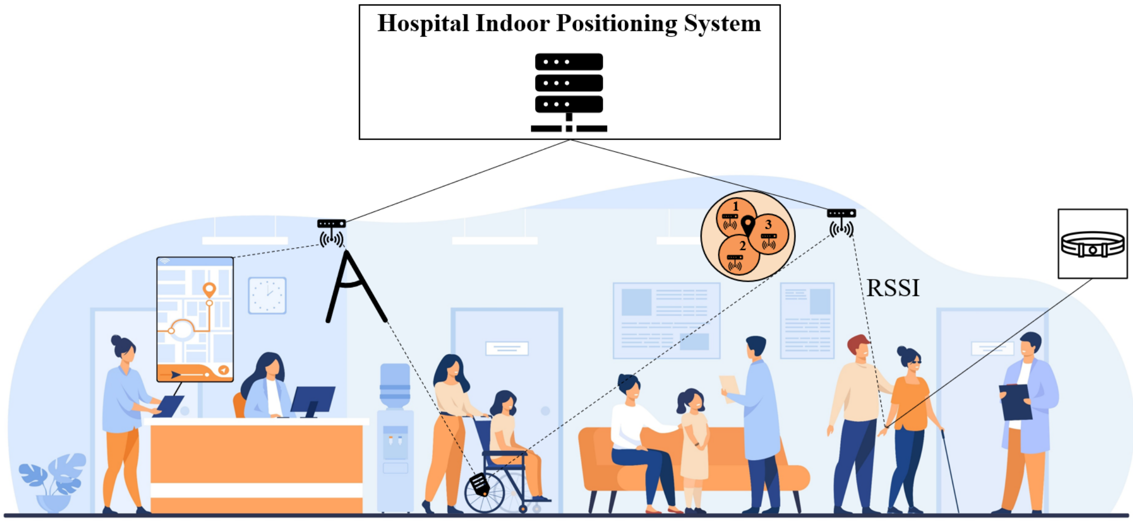


*Figure 15: Functional setup of an exemplary IPS in a hospital [60] (Image sources: [34, 43, 44, 53]).*

## 3.3 Methods

As the methodology for this research, the Scoping Review approach by Arksey and O'Malley [6] was used. It is dedicated to "map" the relevant literature in the field of interest [6] and provides a search strategy, a standardized data extraction form and a risk of bias assessment [39]. This study examines IPS in hospitals to solve in-hospital IPS tasks. As the sole restriction, the published articles had to be in English. No publication date limitations were imposed. This search was applied to the literature databases Scopus (determined time frame: 2006 – 2020), IEEE (Institute of Electrical and Electronics Engineers / 1994 – 2020) and AISeL (Association for Information Systems Electronic Library / 2005 – 2017). The research was conducted from January 2020 to February 2021, with the last search run on 01 March 2021. The study was concluded from March to August 2021. Accordingly, the search strategy is presented [39]:

The following terms were used to conduct the search process: hospital, clinic, indoor navigation, indoor localization, object localization. The search queries for the databases AISeL, IEEE and Scopus are presented in section 3.7.1. Then, the studies were evaluated and determined as "relevant" or "not relevant" by a three-step investigation. First, the abstracts of the studies were reviewed, and they had to match the following first-order inclusion criteria:

1. The environment of the research is, at least, one hospital.
   AND
2. The study addresses the aim of navigating or tracking individuals through the hospital.
   AND / OR

3. The research addresses the aim of localizing objects in the hospital.

Second, duplicates that were determined through different databases were removed. Third, the studies were analyzed in-depth. Therefore, relevant studies had to match the following second-order inclusion criteria:

1. The IPS was tested and / or implemented in a real hospital scenario or designed for a hospital use case and is therefore in preparation to be implemented in a hospital scenario.
2. The IPS determines the position of an object and / or a person by a localization technique (eg, trilateration – see Table 2). For example, an IPS that gives directions due to a location that the user must determine manually (eg, by selecting it as the own position) is considered irrelevant for this research.
3. If the IPS is dedicated to navigate robots through hospitals, the respective study is considered irrelevant. Concerning the fact that the localization of robots has to be much more precise than those of people, since significantly more environmental factors, such as obstacles, have to be considered, this leads to higher costs for robot IPS than for more convenient IPS [23]. As costs are important to evaluate IPS (see section 3.3), considering robot IPS would have caused a bias within the IPS evaluation results.

The abstracts and full-texts were reviewed by the author and one reviewer independently of each other, ie, blinded, to determine whether a research will be included in this study or not. The reviewer is not an author as he did it as part of his job, however, not a subordinate of the author. To report on the differences of this independent procedure (and for risk of bias assessment [39]), the Cohen's kappa coefficient [38] was used. Thereby, a kappa value of .526 was determined that represents a moderate agreement between the author and the reviewer, according to [38]. Subsequently, disagreements between the author and the reviewer concerning the first- and second-order inclusion criteria that were applied to the studies were solved by consensus. The author then performed the evaluation of the included studies, leading to the results (see tables 1 to 3) and limitations (see A-3 to A-11) of this study. To collect the data, a standardized extraction form [39] was designed (based on the Cochrane Consumers and Communication Review Group's data extraction template [49] that was adapted for IPS research purposes based on [6, 31, 65] by the author). The data sheet contains: database; publication year; author(s); title; duplicate-check; abstract / first-order inclusion criteria: 1. hospital, 2. tracking / navigating individuals, 3. object localization; conference/journal details; in-depth analysis / second-order inclusion criteria: brief summary; 1. tested / implemented in hospital scenario, 2. live-determination of position, 3. no robot navigation; relevant to be included in review? (author + reviewer); notes (author); exclusion criteria / consensus between author and reviewer; study design; results: evaluation framework results; limitations; notes for results / limitations (author). For a better understanding, Figure 2 reflects the study selection process of the author. The study selection process of the reviewer will be provided as additional data for this research.

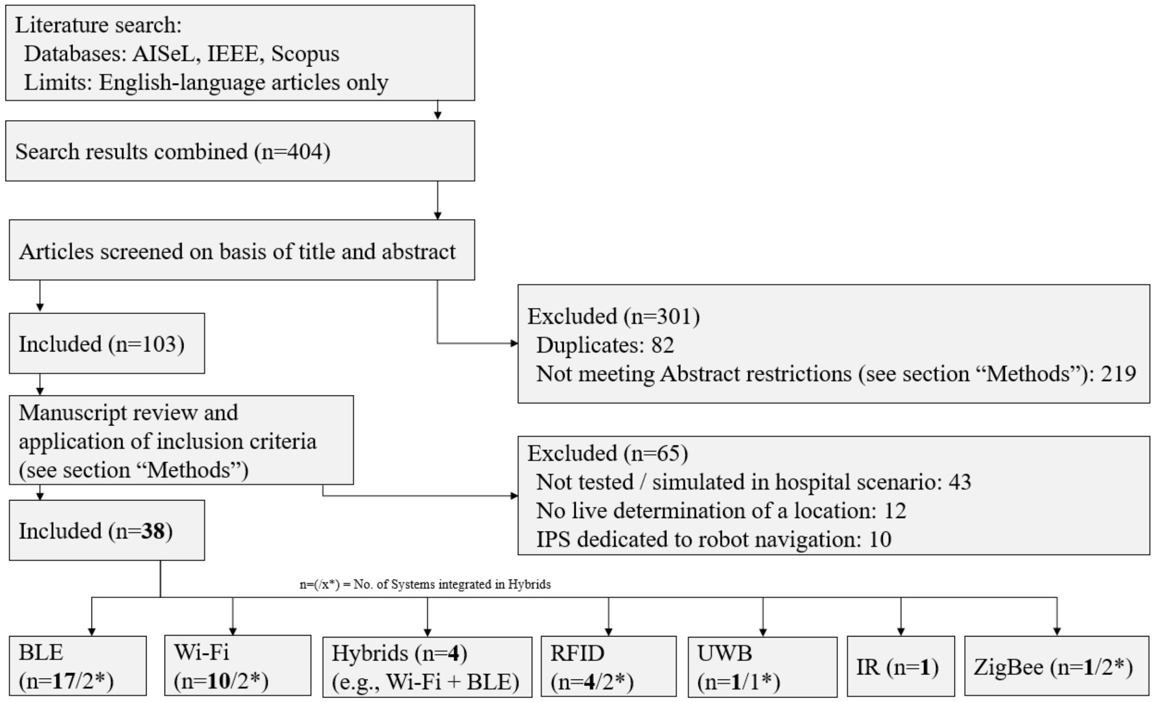

*Figure 16: Study selection flowchart (adopted from Fuccio et al., Liberati et al. [13, 29])*

For appropriate evaluation of IPS in hospitals and to gather the participants (P), interventions (I), comparators (C), outcomes (O) as well as the study designs (S), the PICOS approach as part of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework guidelines according to [29] was used. To specify the participants (P), the term "hospital" represents a specific location where individuals receive medical care for a certain amount of time [62]. This definition specifically includes integrated and additional business segments of a hospital, such as an elderly care center, but excludes medical care interventions at alternating locations, eg, integrated home care [20]. To determine the study design of a relevant research (the "S" in PICOS approach [29]), design evaluation methods according to Hevner et al. [15] were used, who distinguished between: observational- (case- and field studies); analytical- (statistic-, architecture-, and dynamic analyses as well as optimization); experimental- (controlled experiment or simulation); testing- (functional- or structural testing); or descriptive (informed arguments and scenarios) methods as study design. Accordingly, this research considers studies that: a) describe the implementation of an IPS and different scenarios to test the IPS and therefore fulfill the requirement of a "case study" according to [15]; b) represent experiments [15] that were conducted in a hospital or in an environment that was specifically prepared to illustrate a hospital (eg, prepared university labs to simulate an emergency department waiting hall in a hospital [17]); as well as c) simulated systems [15], whose development was clearly related to a hospital scenario, eg, a system to prevent the kidnapping of newborns [28] or to call nurses in case of emergency [21]. As comparatives (C), the IPS were sorted using criterion sampling methods [2, 42] to determine the practical aim of the respective IPS (see Table 3). Additionally concerning the technical IPS concepts, characteristics were derived from [31, 65] who proposed a highly cited evaluation framework for IPS. Therefore, the systems were sorted concerning: 1) the technology of the IPS (eg, Wi-Fi, BLE); 2) the localization technique (eg, RSSI) as well as; 3) prediction-improving methods that enhance the IPS accuracy. To evaluate the IPS (as "outcomes" as the "O" of the PICOS approach [29]), [31, 65] defined relevant criteria therefore. They are: (i) accuracy, (ii) availability, (iii) cost due to additional hardware, (iv) energy efficiency, (v) latency/delay, (vi) precision, (vii) reception range, (viii) robustness, as well as (ix) scalability [31, 65]. In this research, those aspects are used to distinguish the relevant IPS for hospitals, as evaluation results were gathered according to the evaluation parameters of [31, 65] and expected and unexpected limitations of those investigations are assigned to the respective parameters. While the results are demonstrated in tables 3 to 5, detailed explanations of the limitations in accordance with the evaluation characteristics are presented in the appendix (see section 3.7.3 to 3.7.11). First, the respective IPS accuracy (declared in meters) helps to compare the relevant studies among themselves by presenting the exactitude of the localization results (declared in meters) [31, 65] (see section 3.7.3). Second, availability refers to whether the system utilizes techniques that do not need additional hardware, instead utilizes signals (eg, Wi-Fi, BLE) that are already available on common devices (eg, smartphones) [65] (see section 3.7.4). Third, IPS setups should require no or minimal additional costs due to additional hardware [31, 65] (see section 3.7.5). Fourth, to protect device batteries, the IPS should be energy efficient [31, 65] (see section 3.7.6). Fifth, the latency/delay of the IPS should be low to reduce the possibility of localization errors [65] (see section 3.7.7). Sixth, whereas the accuracy considers the (absolute) values of the mean distance errors, the precision represents the (relative) consistence of the system instead, as it reveals the variation of its performance over many trails [31] (see section 3.7.8). Seventh, the reception range refers to the range of the signal that is emitted by reference points (eg, routers) and received by devices (eg, smartphones), as higher ranges often lead to lower accuracies but also lower costs and vice versa [31, 65] (see section 3.7.9). Eighth, the IPS should be robust in terms of system failures and disfunctions because of new tasks for the respective IPS [31] (see section 3.7.10). Nineth, the scalability of the IPS should be high, so that new tasks/areas of implementations (eg, asset tracking/hardware stores) can be easily processed by the system [65] (see section 3.7.11). Furthermore, Figure 17 represents the overall research process of this study.

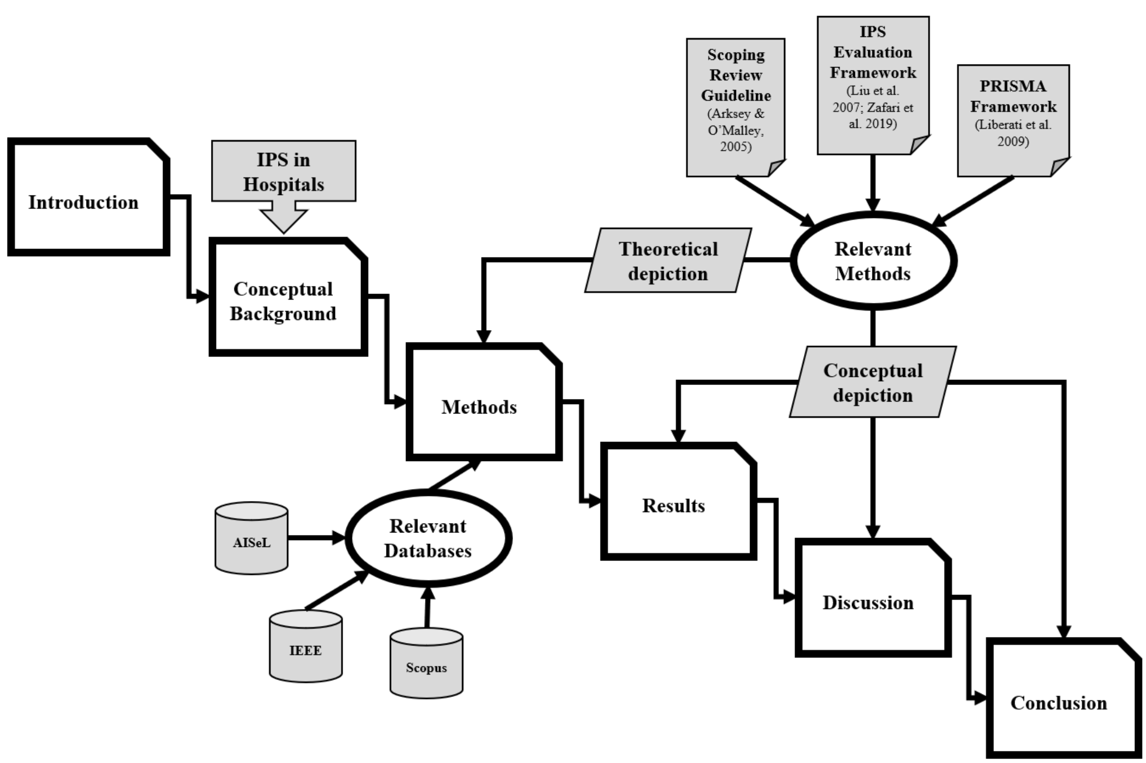


Figure 17: Research process

## 3.4 Results

The search of AISeL, IEEE and Scopus database provided 404 results. After adjusting for duplicates, 82 articles were removed. Additionally, 219 studies were discarded, as they did not meet the title and abstract criteria defined in section 3.3. The remaining 103 articles were reviewed in-depth and checked whether they fulfill the inclusion criteria. Thereby, 65 studies were excluded, as they were neither dedicated, nor tested or simulated in a hospital scenario (n=43), the position determination of the IPS was not live (n=12), or the IPS was dedicated to robot navigation (n=10). Hence, a total of 38 studies was included in the review.

To gather the results, the PICOS approach was used. A detailed depiction of the participating (P) hospitals is presented in section 3.7.2. For the interventions (I), the following Table 3 presents the research objectives of the relevant studies to encounter localization-related problems in hospitals. As expected, all studies considered the tracking and navigation of / to people or devices, with some studies tackling more granular issues (eg, to prevent the kidnapping of newborns / to track patients / workers exercising tasks to find behavioral patterns).

*Table 3: Objectives of the relevant IPS studies for hospitals.*

| **Topics** | **References** |
|---|---|
| tracking and navigation of / to people or devices | [1, 3, 7, 17, 46, 48] |
| +indoor- and outdoor IPS | [4, 14] |
| +to ensure compliance measures | [22] |
| +to prevent stealing of assets | [56] |
| +to manage emergency situations | [21, 27, 61] |
| +to prevent kidnapping of newborns | [26, 28] |
| +to dissolve overcrowded emergency departments | [16] |
| +to design a patient-centered smart hospital | [64] |
| +to design a navigation system dedicated to elderlies | [5] |
| +to design an augmented reality-based IPS | [19] |
| +to access control, to generate real-time system alarm | [51] |
| +to direct virtual care | [58] |
| +to track hospital beds | [9, 30, 32, 40] |
| +to develop a waypoint-based indoor navigation system | [10] |
| +to use heuristics / clustering in tracking | [8, 47, 50, 57, 63] |
| +to design an IPS for urgent care | [25] |
| +to compare different IPS technologies | [37] |
| tracking of patients / workers exercising tasks to determine behavioral patterns | [18, 35, 36, 45, 54, 55] |

To distinguish between existing IPS, attributes are needed to compare ("C" in PICOS [29]) the results. Therefore, Liu et al. [31] and Zafari et al. [65] conducted highly relevant studies to distinguish and evaluate IPS. They state that different localization techniques (such as trilateration, see section 3.2) can be utilized by different localization technologies (such as Wi-Fi or Bluetooth) [31, 65]. As the complexity of the algorithm (as the foundation of the localization technique) is more important than the raw choice of technology for IPS purposes [57], those criterions (localization technology and technique) are used in this research to gather the results following criterion sampling methods [2, 42]. Then, the criterions are assigned to the taxonomy of smartphone-localization techniques according to [33]. Additionally, prediction-improving methods are gathered, as they improve the IPS performance [37] and represented in Table 4.

*Table 4: Technologies, techniques, and prediction-improving methods of IPS in hospitals*

| **Localization Technology** | **Localization Technique (/ specified method (if any))** | | **Prediction-Improving Method** | **References** |
|---|---|---|---|---|
| **Wi-Fi** | RSS-based | Distance | non-disclosed | [17] |
| | | Fingerprinting | non-disclosed | [14, 57, 61] |
| | | | k Nearest Neighbor (kNN) | [32, 63] |
| | | | Support Vector Machine | [9] |
| | | | Stride Estimation, kNN | [7] |
| | | Radio Map[6] | Particle filtering | [37] |
| | | | Temporal filter | [37] |
| | | Table based | non-disclosed | [61] |
| | | Trilateration | non-disclosed | [14, 57] |
| | | Weighted Centroid Localization | non-disclosed | [55] |
| | | | Particle filtering | [37] |
| | | | Temporal filter | [37] |
| | Time-based | ToA (Time of Arrival) (/Trilateration) | non-disclosed | [21] |
| | Angle-based | AoA (Angle of Arrival) (/Triangulation) | non-disclosed | [17, 21] |
| | Dead reckoning | Pedestrian Dead Reckoning | non-disclosed | [5, 7] |
| **BLE** | RSS-based | Acceleration | non-disclosed | [26] |
| | | | Random Forest Classifier | [45] |
| | | Distance | non-disclosed | [19] |
| | | Distance Measurement Error | non-disclosed | [28] |

[6] extended Version of Signal Strength Path Loss Model

| | | | | |
|---|---|---|---|---|
| | | Dynamic Accuracy Estimation | non-disclosed | [4] |
| | | Fingerprinting | non-disclosed | [16, 50, 57, 64] |
| | | | Model Learning | [47] |
| | | | Weighted kNN | [50] |
| | | Least Square Estimation | non-disclosed | [40] |
| | | Long-Distance Path-Loss model | non-disclosed | [48] |
| | | Strongest Signal | non-disclosed | [10, 26, 30] |
| | | Trilateration | non-disclosed | [22, 57] |
| | | Weighted Average | non-disclosed | [3] |
| | | Weighted Centroid Localization | non-disclosed | [57] |
| | Angle-based | AoA (/Triangulation) | non-disclosed | [56] |
| | Proximity | non-disclosed | non-disclosed | [22, 35, 36] |
| | | Machine Learning, Decision Tree, Semantics | non-disclosed | [58] |
| **Radio Frequency Identification (RFID)** | RSS-based | Fingerprinting | non-disclosed | [1, 8, 27] |
| | | Strongest Signal | non-disclosed | [51] |
| | | Trilateration | non-disclosed | [21] |
| | Angle-based | AoA (/Triangulation) | non-disclosed | [51] |
| | Time-based | Random Forest Classifier | non-disclosed | [54] |
| **ZigBee** | RSS-based | Fingerprinting | non-disclosed | [57] |
| | | | kNN, Particle filtering | [18] |

| | | | | |
|---|---|---|---|---|
| | | Trilateration | non-disclosed | [57] |
| | RSS- + Time-based | Spray | non-disclosed | [57] |
| | Timestamp (added to BLE data) | non-disclosed | non-disclosed | [48] |
| **Ultra-Wideband (UWB)** | Time-based | ToA (/Probability) | non-disclosed | [46] |
| | Time-based | Random Forest Classifier | non-disclosed | [54] |
| **Infrared (IR)** | Periodical IR signals | Identification Code | non-disclosed | [25] |

As the outcomes of this research (and of the PICOS approach [29] – "O"), this scoping review reflects current and future IPS in hospitals by determining that Wi-Fi and BLE are the most common technologies used in this context (see Figure 16, Table 4). Furthermore, RSS-based localization techniques are widely used, which is congruent with general IPS research [65]. By considering prediction-improving methods, a variety of approaches exist that improve the IPS accuracy (see Table 4). Concerning the performance of the IPS, evaluation criteria [31, 65] were used to assess IPS (see section 3.3) and are presented in the following table. The data for (i) accuracy is either self-reported (in meters) or not available (N/A). The (ii) availability is determined either "good" if the IPS is processable by most of the current smartphones and "poor" if not. The evaluation of (iii) cost due to additional hardware refers to whether additional hardware is used or not. Regarding (iv) energy efficiency, an IPS is either determined "high" if it does not drain batteries or "low" if it does. The (v) latency/delay of the IPS is determined "low" by reacting within milliseconds, otherwise it is considered "high". (vi) precision is either self-reported (in percent) or not available (N/A). A (vii) reception range of more than 10 meters between the measurement points is considered "good" to keep the (iii) cost low [65], otherwise it is determined "poor". (viii) robustness is either "good" or "poor" (self-reported). For a "high" (ix) scalability of an IPS, it has to been tested with multiple devices, otherwise it is determined "low". If criteria were not addressed by the study sufficiently, they were considered not available (N/A).

*Table 5: Evaluation results of IPS in hospitals*

| Aim of the System: tracking and navigation of / to people or devices (see Table 3) (Authors [References]) | Technology (Technique) | (i) | (ii) | (iii) | (iv) | (v) | (vi) | (vii) | (viii) | (ix) |
|---|---|---|---|---|---|---|---|---|---|---|
| +to design a navigation system dedicated to elderlies (Aoki et al. [5]) | Wi-Fi (RSS-based) | N/A | poor | yes | low | N/A | 93.3% | N/A | poor | low |
| (Bao et al. [7]) | Wi-Fi (RSS) | 2.31m | good | no | N/A | low | 88% | good | poor | high |
| (Chriki et al. [9]) | Wi-Fi (RSS) | N/A | good | no | N/A | high | 88.38% | good | N/A | N/A |
| +indoor- and outdoor IPS (Gouin-Vallerand et al. [14]) | Wi-Fi (RSS) | 2.20-4.49m | good | yes | N/A | high | 82% | poor | N/A | high |
| (Lu et al. [32]) | Wi-Fi (RSS) | 3.73m | good | yes | high | N/A | 94.25% | good | good | low |
| (Mathisen et al. [37]) | Wi-Fi (RSS) | 2.95m | good | no | N/A | high | 95.78% | good | poor | high |
| tracking of patients / workers exercising tasks to find behavioral patterns (Stisen et al. [55]) | Wi-Fi (RSS) | N/A | good | yes | high | high | 89.2% | good | poor | N/A |
| +to manage emergency situations (Wille et al. [61]) | Wi-Fi (RSS) | N/A | good | yes | low | high | N/A | N/A | poor | high |
| (Yogaprakash et al. [63]) | Wi-Fi (RSS) | 2.54m | good | yes | high | N/A | 72% | good | poor | N/A |
| +to manage emergency situations (Kanan et al. [21]) | Wi-Fi (Time-based) + (Angle-based) + RFID (RSS) | 2-3m | good | yes | high | low | N/A | good | N/A | high |
| (Hou et al. [17]) | Wi-Fi (Angle) | 2.5m | good | yes | high | high | N/A | good | N/A | low |
| (van Haute et al. [57]) | Wi-Fi (RSS) + BLE (RSS) + ZigBee (RSS) + (Time) | Wi-Fi: 2.68m BLE: 3.12m ZigBee: 3.08m | good | yes | high | N/A | Wi-Fi: 46.58% BLE: 61.64% ZigBee: 49.32% | good | good | low |
| (Anagnostopoulos (2014) [3]) | BLE (RSS) | .97m | good | yes | high | high | N/A | poor | N/A | high |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| +indoor- and outdoor IPS (Anagnostopoulos (2015) [4]) | BLE (RSS) | 5-14.99 m | good | yes | low | high | N/A | poor | poor | high |
| (Chu et al. [10]) | BLE (RSS) | 3-5m | good | yes | high | low | 82% | poor | N/A | high |
| +to dissolve overcrowded emergency departments (Ho et al. [16]) | BLE (RSS) | 1.48m | good | yes | N/A | high | N/A | poor | poor | low |
| +to design an augmented reality IPS (Huang et al. [19]) | BLE (RSS) | 3-5m | good | yes | low | high | N/A | poor | N/A | high |
| +to prevent kidnapping of newborns (Ku et al. [26]) | BLE (RSS) | N/A | good | yes | N/A | N/A | 88.24% | good | poor | low |
| +to prevent kidnapping of newborns (Li et al. [28]) | BLE (RSS) | 1.29m | good | yes | N/A | N/A | N/A | poor | N/A | low |
| (Lin et al. [30]) | BLE (RSS) | 3-5m | good | yes | high | high | 97.22% | poor | poor | low |
| (Nguyen et al. [40]) | BLE (RSS) | 0.125-0.37m | good | yes | high | N/A | N/A | poor | N/A | low |
| tracking of patients / workers exercising tasks to find behavioral patterns (Ramezani et al. [45]) | BLE (RSS) | N/A | good | yes | high | low | N/A | N/A | N/A | high |
| (Roy et al. [47]) | BLE (RSS) | N/A | good | yes | high | low | 92% | good | N/A | high |
| (Shipkovenski et al. [50]) | BLE (RSS) | N/A | good | yes | high | N/A | N/A | poor | N/A | N/A |
| +to design a patient-centered smart hospital (Yoo et al. [64]) | BLE (RSS) | 5.48m | good | yes | N/A | N/A | 67.4% | N/A | N/A | high |
| +to ensure compliance measures (Karimpour et al. [22]) | BLE (RSS) + (Proximity) | N/A | good | yes | N/A | high | 92% | poor | N/A | low |
| (Rozum et al. [48]) | BLE (RSS) + ZigBee (Timestamp) | 0.92m | good | yes | N/A | high | N/A | good | poor | N/A |
| +to prevent stealing of assets (van der Ham et al. [56]) | BLE (Angle) | 0.5m | good | yes | N/A | N/A | 70% | N/A | poor | N/A |
| tracking of patients / workers exercising tasks to find behavioral patterns (Marini et al. [35] | BLE (Proximity) | N/A | good | yes | N/A | high | N/A | poor | N/A | high |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| +to direct virtual care (van Woensel et al. [58]) | BLE (Proximity) | N/A | good | yes | high | high | 87.70% | good | good | N/A |
| (Augilar-Garcia et al. [1]) | RFID (RSS) | 1-2m | poor | yes | low | low | N/A | poor | good | high |
| (Calderoni et al. [8]) | RFID (RSS) | N/A | poor | yes | low | N/A | 83% | good | poor | high |
| +to manage emergency situations (Lee et al. [27]) | RFID (RSS) | N/A | poor | yes | N/A | N/A | N/A | poor | N/A | N/A |
| +to access control, to generate real-time system alarm (Silva et al. [51]) | RFID (RSS) + (Angle) | N/A | poor | yes | low | N/A | N/A | good | N/A | high |
| (Steele et al. [54]) | RFID + UWB (Time) | N/A | poor | yes | N/A | N/A | 86.58% | good | poor | high |
| +to direct virtual care (Hsiao et al. [18]) | ZigBee (RSS) | 2.3m | poor | yes | low | N/A | N/A | good | N/A | high |
| (Romme et al. [46]) | UWB (Time) | 0.87m | poor | yes | N/A | low | N/A | poor | N/A | low |
| (Konecny et al. [25]) | Infrared (Periodical IR signals) | N/A | poor | yes | low | low | N/A | poor | N/A | high |

Concerning the limitations of the IPS the evaluation criteria ((i) accuracy to (ix) scalability) [31, 65] were used to gather expected and unexpected limitations. As those limitations are numerous and (mostly) heterogeneous, they are presented in the Appendix, from section 3.7.3 to 3.7.11. Considering the study design (S) of the PICOS approach [29], most studies are experimental (as controlled experiments) or observational (as case studies) according to the definition of Hevner et al. [15].

## 3.5 Discussion

With regard to the analysis of participants, one hospital is especially relevant. The results regarding participating hospitals show that the National Taiwan University Hospital Yun-Lin Branch has been involved in a multitude of IPS studies. Thereby, the hospital is most relevant for those stakeholder groups seeking interchange and helpful insights of IPS implementation and/or development in hospitals. Concerning the evaluation criteria that are used to compare and limit the existing IPS, this study led to several propositions showing the need for further IPS studies.

First, concerning the evaluation framework used and by considering (i) accuracy, Wi-Fi based IPS are less accurate than other technologies used for IPS in hospitals. However, together with the BLE based IPS, provide a higher (ii) availability than the other approaches, which supports existing insights concerning IPS [31, 65]. The evaluation of (iii) cost is disputed, as some of the IPS used additional devices other than smartphones without a technical need to do so. The reasons therefore are various, eg, to adapt the IPS to meet certain demands of specific stakeholder groups [5] or to meet the overall aim of the IPS [55, 63]. Unfortunately, reports about (iv) energy efficiency are disputed as well, as they are often not available, despite the fact that (iv) energy efficiency is important for IPS, since some studies addressed this aspect accurately (eg, [47, 58, 61]). The same holds true for (v) latency/delay, as details are often not available or a high (v) latency/delay is considered less important for the aim of the IPS, as eg, a live determination of a position within milliseconds is not necessary for the overall aim of the IPS (eg, [22, 55, 61]). Regarding (vi) precision, most of the IPS obtained high values concerning the fulfillment of their IPS tasks. Therefore, the values of (vi) precision should be handled cautiously, as every study developed their own evaluation criteria to assess the IPS performance, leading to mere (vi) precision values without demonstrating the estimation of them (eg, [5, 7, 63]). Surprisingly, some IPS failed to achieve a sufficient (vii) reception range compared to ascertained reception ranges for specific IPS technologies (such as Wi-Fi and BLE [31, 65]) and (i) accuracy of other IPS. As some of them chose to keep the distance between the measurement points lower than 10m (eg, [10, 14]), using more measurement points than technically necessary [31, 65], probably to increase (i) accuracy [65], other IPS that achieved sufficient (vii) reception range also reached a higher (i) accuracy (eg, [37, 48]). Concerning the (viii) robustness, it is likely that more than those IPS evaluated as "poor" determined problems/concerns that limit their IPS while implementing/testing their system, as statements about (viii) robustness were often not available. Nonetheless, some studies reported their problems/concerns concerning (viii) robustness adequately (eg, [8, 58]). Whereas (ix) scalability in [65] was defined as: "we require the system to support multiple device for scalability", this study requires that the respective IPS has been tested with more than one device to be able to verify (ix) scalability. Given that, a surprising amount of IPS (10) have not been verified with more than one device. Again, several studies did not report their experiences concerning the (ix) scalability of their IPS.

Based on the results of the evaluation framework, there are research gaps regarding IPS in hospitals that should be addressed in the future. First, the algorithms of IPS should be addressed in further studies, which is supported by [57] stating that: "the complexity of the algorithm is more important than the raw technology choice". The results show that IPS that used the same technology performed differently, with eg, BLE-IPS that were tested in a hospital in a larger space achieving (i) accuracy from 1.48 meters [16] as the mean error compared to similar IPS in a larger space that achieved (i) accuracy of 3 to 5 meters [10], despite the fact that the study of [10] is more recent. One possible explanation is the prediction improving method used, as an important factor in determining the (i) accuracy of the IPS according to [31, 65]. Whereas [16] used fingerprinting as a prediction improving method, [10] incorporated the strongest signal for position determination, indicating that fingerprinting is better suited for BLE-IPS in hospitals than the strongest signal for position determination in larger spaces. Future research should thus investigate the prediction improving methods presented in this study to the respective IPS technologies to verify which prediction improving method is best suited for the respective IPS technology by addressing multiple prediction improving methods for IPS in different hospitals in large spaces.

Second and simultaneously, those studies should address the evaluation framework proposed in [31, 65] to enhance the comparability between the different IPS in hospitals and to verify the propositions of [31, 65] regarding IPS in hospital contexts. Until now, the overall evaluation of IPS in hospitals is limited, as the presentation of most of the IPS in this study is, measured against the criteria of the evaluation framework according to [31, 65], is inadequate. For instance, some IPS required high (iii) cost, while providing a poor (vii) reception range (which is likely, due to the use of more devices than necessary [31, 65]) and achieving poor results in (i) accuracy (eg, [10, 19, 30]). In contrast, other IPS required low (iii) cost, while providing a good (iii) reception range and achieving better results in (i) accuracy (eg, [7, 37]). As this may belong to the algorithm of the IPS (that leads to good (i) accuracy, respectively [31, 65], the handling of an appropriate IPS is too complex to evaluate it using mere (i) accuracy as a measure to compare IPS [58]. Therefore, the reasons for different IPS performances will be more clear and further Scoping Reviews concerning IPS in hospitals will be more precise, if the IPS are to be evaluated using the same evaluation framework. Besides, the evaluation framework itself could be further evaluated, eg, concerning a ranking of the different evaluation criteria of the framework by interviewing stakeholders (such as (i) researcher who investigate the adoption, diffusion, and evaluation of IT for hospitals, (ii) IT developers for hospitals, and (iii) hospital management) and by analyzing the relationships between the evaluation criteria, as some of them seem to be dependent of each other, such as (iii) cost and (vii) reception range.

## 3.6 Conclusion

This research investigates current and future IPS in hospitals by reviewing relevant studies obtained from the literature databases AISeL, IEEE and Scopus using the Scoping Review method. It was conducted using the PRISMA Framework and PICOS approach [29] to gather the results. To critically assess the IPS, the highly cited evaluation framework for IPS according to Liu et al. [31] and Zafari et al. [65] was used and current and future IPS in hospitals gathered and evaluated concerning: IPS technology, technique and prediction-improving method as well as: (i) accuracy, (ii) availability, (iii) cost, (iv) energy efficiency, (v) latency/delay, (vi) precision, (vii) reception range, (viii) robustness and (ix) scalability [31, 65].

This study provides several theoretical implications. First, this research contributes to our knowledge about IPS in hospitals by presenting the (1) technology, (2) techniques, (3) prediction-improving methods, (4) evaluation results as well as (5) limitations during testing/implementing IPS in hospitals. The highly cited evaluation framework for IPS [31, 65] ensured that a sufficient comparability to assess IPS was given. Unfortunately, only few studies utilized the evaluation framework to assess their IPS, leading to a limited evaluation of all IPS in hospitals and the insights of this study, respectively. Therefore, and to improve further IPS reviews, the author of this study strongly encourages researcher to use the evaluation framework to assess their IPS. Additionally, future research should focus on improving the evaluation framework. Currently, all the evaluation criteria ((i) to (ix), see section 3.3) are considered as equally important. Given that, it is likely that stakeholders with partly opposing interests (such as hospital management and IPS developers) could consider certain evaluation criteria ((i) to (ix)) more important than others, demonstrating the need to rank those evaluation criteria and therefore to provide a weighted framework to assess IPS (in hospitals).

As practical implications, the insights of this study can be used by (i) researchers who investigate the adoption, diffusion, and evaluation of IT for hospitals, (ii) IT developers for hospitals, and (iii) hospital management that try to determine an appropriate IPS for their hospital, as (1) application scenarios for IPS in hospitals were determined (represented by the objectives of the studies, see Table 3) that could be relevant for other hospitals seeking to implement an IPS. (2) Hospitals seeking to implement an IPS can use the perceptions of this study (IPS technologies, techniques, prediction-improving methods, the evaluation and limitations of IPS in hospitals) to determine an IPS technology that satisfies their demands towards IPS in hospitals. Decision makers in hospitals benefit from this study by obtaining an evaluation of existing IPS approaches in hospitals, which can help them to decide which IPS technology to adopt. This evaluation can be used in conjunction with the prediction improving methods to define the IPS technology, technique as well as prediction improving method for their IPS in question.

Ultimately, this research is limited, as every study. As the databases AISeL, IEEE and Scopus were used to gather relevant studies, other databases (such as Web of Science or Google Scholar) could lead to different results. This could also be subject of further studies. Additionally, this research does not consider IPS in hospitals that are dedicated to robot navigation. Thereby, this study is only partially relevant for researchers or hospital management seeking to implement an IPS in a hospital dedicated to robot navigation.

## 3.7 Appendix

### 3.7.1 Search Strings for Literature Databases

#### *3.7.1.1 AISeL*

“indoor navigation” OR “indoor localization” OR “object localization” AND “hospital” OR “clinic”

#### *3.7.1.2 IEEE*

(indoor navigation OR indoor localization OR object localization) AND (hospital OR clinic)

#### *3.7.1.3 Scopus*

TITLE-ABS-KEY ((“indoor navigation” or “indoor localization” OR “object localization”) AND (“hospital” OR “clinic”))

### 3.7.2 Participating Hospitals

| Hospital Name | Country | Research |
|---|---|---|
| Perugia Hospital | Italy | [3, 4] |
| Cleveland Clinic (Avon Tower) | USA | [7] |
| National Taiwan University Hospital Yun-Lin Branch | Taiwan | [10, 16, 18, 19, 27, 30, 32] |
| Jewish General Hospital of Montreal | Canada | [14] |
| Sint-Jozefskliniek Hospital Izegem | Belgium | [57] |
| University Hospital of Ostrava | Slovakia | [25] |
| Northern Health Hospital Melbourne | Australia | [35, 36] |
| Hospital Padre Américo Penafiel | Portugal | [51] |
| IWK Hospital Halifax | Canada | [47] |
| Eugene J. Towbin Healthcare Center | USA | [54] |
| Rijnstate Hospital | Netherlands | [56] |
| University Hospital of Mainz | Germany | [61] |
| Seoul National University Bundang Hospital | South Korea | [64] |

### 3.7.3 Accuracy

| **Unexpected Limitations** | **Research** |
|---|---|
| The IPS accuracy is lower and / or the rapidity is slower than possible, due to the simplicity and / or affordability of the respective IPS. | [10, 21, 22, 58, 61] |
| The IPS accuracy decreases, if two or more navigating individuals pass each other. | [10] |
| The addition of a gyroscope to mitigate the random fluctuation of RSSI is appropriate to improve the IPS accuracy. | [32] |
| Locations with similar proximity data should be grouped for improved IPS accuracy. Nevertheless, a specific number of groups must be outdone (eg, 6 in this research), since fewer groups (eg, than 6) lead to lower positioning accuracy. | [47] |
| The IPS accuracy decreases if the individual that holds the devices moves faster through the test area. | [54] |
| AoA as the IPS localization technique led to higher accuracy than the RSSI Range-Based Method. | [17] |
| The selection (or development) of an appropriate localization technique (and prediction-improving method / see Table 4) is more important than of the raw IPS technology (eg, BLE or Wi-Fi). | [57] |
| To improve Wi-Fi based IPS accuracy, Random Forest outperformed C.45 Decision Tree, Support Vector Machine as well as k-Nearest Neighbor as the most effective prediction-improving method. | [55] |

| **Ranges of Accuracy** | **Research** | **Related Technologies** |
|---|---|---|
| 0.0 – 0.49 meters | [40] | BLE |
| 0.5 – 1.0 meters | [3, 46, 48, 56] | UWB ([46]); BLE ([3, 48, 56]) |
| 1.01 – 1.99 meters | [1, 16, 28] | RFID ([1]); BLE ([16, 28]) |
| 2 – 2.99 meters | [7, 17, 18, 21, 37, 63] | ZigBee ([18]); Wi-Fi ([7, 17, 21, 63]); |
| 2 – 4.99 meters | [14, 57] | Wi-Fi ([14, 57]); BLE ([57]); ZigBee ([57]) |
| 3 – 5.99 meters | [10, 19, 30, 32, 64] | BLE ([10, 19, 30, 64]); Wi-Fi ([32]) |
| 5 – 14.99 meters | [4] | BLE |
| 10 – 19.99 meters | [61] | Wi-Fi |

### 3.7.4 Availability

| **Expected Limitations** | **Research** |
|---|---|
| The IPS utilizes a technology whose signals are not processible by most of the current smartphones. | [46, 48, 54, 57] |
| The IPS need a line of sight to the device. | [17, 46] |
| By now, the IPS (that is based on recognition patterns) is limited to a specific target group only (eg, hospital workers with an a priori definable daily routine). | [55] |
| **Unexpected Limitations** | **Research** |

| | |
|---|---|
| The IPS utilizes smartwatches to detect the physical activity of older patients that undergo subacute rehabilitation. Those smartwatches were a critical barrier in the availability of the localization process, as (a) the hospital has to buy those smartwatches and (b) older participants are often unfamiliar with new technologies (eg, smartwatches) and tend to remove the smartwatch from their wrist before the end of the experiment. | [45] |
| It is uncertain, whether the IPS will operate appropriately in a section that contains several signal frequencies, due to its own medical meaning (eg, x-ray departments), or not. | [37] |
| Smartphones with poor Bluetooth Antennas obtain interferences in receiving the navigational signals of the IPS. | [19] |
| During the IPS process, reconnection errors occurred. | [63] |
| The handling of the IPS was more complicated for older than for younger participants. | [64] |

### 3.7.5 Cost

| **Expected Limitations** | **Research** |
|---|---|
| The IPS has not been tested in a real hospital scenario (and is therefore designed for hospital use cases only), which limits the validity of the respective IPS concerning the anticipated costs to implement and maintain the system. | [1, 5, 9, 17, 21, 28, 30, 40, 56] |
| The IPS has been tested in a specific area / department of the hospital only, which means that the validity of the respective IPS concerning the anticipated costs to implement and maintain the IPS is limited. | [3, 4, 7, 8, 10, 14, 16, 18, 19, 22, 25–27, 32, 35, 37, 45, 46, 48, 50, 51, 54, 57, 58, 61, 63] |

### 3.7.6 Energy Efficiency

| **Unexpected Limitations** | **Research** |
|---|---|
| The IPS is not energy efficient. | [4, 18, 25, 48, 51, 61] |

### 3.7.7 Latency/Delay

| **Unexpected Limitations** | **Research** |
|---|---|
| The transition between the different anchors (as the reference points, see section 3.2) caused inaccuracies / delays during the IPS. | [3, 4] |
| As ZigBee was utilized to transfer the data between the anchors, it has proven to be insufficient because of low speed and high latency. | [48] |
| Because of the complexity of the IPS, the visual display of the user's current position is slightly delayed (position fix for four seconds with updates every two seconds). | [58] |
| The location engine selected (Aruba Location Engine) cannot be judged real time for IPS, as the latency of the engine is high. | [14] |

### 3.7.8 Precision

| **Success rate (in %) of correct routings** | **Research** |
|---|---|
| 97.22% (95% Confidence Interval = 95.90% - 98.55%) | [30] |
| 95.78% (Majority Voting) | [37] |
| 94.25% | [32] |
| 93.3% (Dead Reckoning + RSSI) | [5] |
| 92% | [47] |
| 92% (23 of 25 cases / trilateration) | [22] |
| 89.2% (F1-Score) | [55] |
| 88.38% (in multifloor buildings) | [9] |
| 88.24% (in 7m² test area / strongest BLE signal) | [26] |
| 88% (in PDR method) | [7] |
| 87.7% (original / 2 heuristics) | [58] |
| 87% (in movement detection) | [45] |
| 86.58% (distance traveled) | [54] |
| 83% (in 98% of the cases) | [8] |
| 82% (133 cases of 162 cases overall) | [10] |
| 82% (F1-Score) | [14] |
| 80% (20 of 25 cases / proximity) | [22] |
| 72% (% of errors below 5m) | [63] |
| 70% | [56] |
| 67.4% (average success rate of tasks solved through IPS) | [64] |
| 61.64% (BLE / all anchors) | [57] |
| 49.32% (ZigBee / all anchors) | [57] |
| 46.58% (Wi-Fi / all anchors) | [57] |

| **Unexpected Limitations** | **Research** |
|---|---|
| The error rate of the IPS is higher, if two rooms are not divided through a wall. | [9] |
| As the IPS is dedicated to verify hospital workflows, the error rate of the IPS depends heavily on the granularity of the pre-defined workflows. | [35] |
| One or few base stations for RFID signals (in a space of 526m²) lead to a poor performance. | [1] |
| The trilateration mode (utilizing BLE) as the localization technique led to a better performance than the proximity-based approach. | [22] |

### 3.7.9 Reception Range

| **Unexpected Limitations** | **Research** |
|---|---|
| The average reception range for RF transmission (Wi-Fi) inside a hospital is about 25m. | [21] |
| The average reception range for IR transmission inside a hospital is about 10m and the IR signals do not travel through walls. | [25] |

| | |
|---|---|
| With 6 meters between the beacon nodes, the average positioning accuracy of RFID inside a hospital is 1 to 2m. | [27] |
| To calculate a position within one room by using iBeacons (and BLE), they should be placed around the centre of the room and not in the corners to gain better results. | [28] |
| It remains unclear, how the UWB position estimation of the IPS operates with a bandwidth below 500 Mega-Hertz. | [46] |
| As the reception range varies heavily (about 20% accuracy within 7m²) in the test environment that is one room (without any obstacles mentioned), it seems like the IPS is heavily dependent on the direction of the Bluetooth Antenna(s). | [26] |

### 3.7.10 Robustness

| **Unexpected Limitations** | **Research** |
|---|---|
| Using single RFID signals instead of RFID signal sequences lead to outliners in the IPS process and therefore limited availability. | [8] |
| The performance of the IPS is impaired by the reflection of computer screens. | [56] |
| The IPS is unable to estimate a user's heading direction while walking and not reliable concerning the RSSI signal if the beacons are placed in a different position than the test scenario. | [16] |
| If the cellular structure changes (eg, using global system for mobile communications instead of universal mobile telecommunications system), it could be necessary to create a new fingerprint for the IPS process. | [1] |
| The IPS process fails if the actual route is longer than the premeasured one. | [5] |
| The PDR method caused error accumulation problems. | [7] |
| Adjacent subareas created by iBeacon nodes within 5 meter can cause interruptions in determining the position. | [30] |

### 3.7.11 Scalability

| **Expected Limitations** | **Research** |
|---|---|
| The validity of the IPS concerning object localization is limited, as only one specific device / one kind of device was tested (eg, a specific tag or a smartphone). | [17–19, 21, 26, 28, 40, 47, 56, 64] |

### 3.7.12 Study design

| **Study Design** | **Research** |
|---|---|
| Controlled Experiment | [1, 3–5, 7–10, 16–19, 21, 22, 25–28, 40, 46, 48, 50, 51, 54–57, 63] |
| Controlled Experiment + Simulation | [32] |
| Case Study | [14, 35–37, 45, 47, 58, 61, 64] |
| Simulation | [28] |

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# 4 Determining Design Criteria for Indoor Positioning System Implementation Projects in Hospitals[7]

*Johannes Wichmann, Thomas Paetow, Michael Leyer, Bisrat Aweno, and Kurt Sandkuhl*

**Abstract**

Indoor navigation systems (IPS) can improve orientation for visitors and patients in hospitals and help employees to track assets. Many hospitals are interested in implementing such systems, but often do not know how to implement them. Current known evaluation criteria miss rankings for the relevance of evaluation criteria for implementing an IPS in hospitals. Our research addresses this research gap and answers the question of which design criteria are relevant for IPS implementation projects in hospitals. An integrated PPDF-TOE framework is used and 5 IPS developers from different companies and 5 hospital IT management representatives from different hospitals are interviewed to provide a weighting of evaluation criteria. In addition, controlled field experiments (CFEs) were conducted. Our results contribute to healthcare information systems research by providing an understanding how design criteria can be derived with the integrated framework and highlight specific design criteria for IPS in hospitals.

[7] The article is currently under review for presentation at the 30th European Conference on Information Systems (ECIS) 2022 in Timisoara, Romania [51].

## 4.1 Introduction

Indoor positioning systems (IPS) are an important building block in the information systems structure of hospitals as they allow to navigate visitors, patients and doctors better reducing navigation times, reaching indoor navigations without detours and thus contributing to an increase of hygiene. Such navigation is especially important for hospitals characterized by many non-frequent visitors and patients, technical devices often being spread throughout the hospital, larger building structures as well as constantly changing layouts for patient and treatment booking. These problems became even more evident in the ongoing Covid-pandemic [50]. While initial systems are available, the overwhelming majority of hospitals has not installed IPS but many are interested [30]. However, next to finances being an issue, a critical aspect is the question how to design the implementation into the hospital environment [55].

Currently, existing evaluation criteria are equally weighted and therefore of equal value, despite being related among each other, as stated by Liu et al. [34] and Zafari et al. [55]. In the context of an IPS implementation, such an equally-weighted IPS evaluation framework is disadvantageous, since important and well-investigated paradigms of information systems development concerning important stakeholders are not considered [18]. There has to be a ranking of the importance of factors to decide how and with which supplier to implement an IPS in a hospital. Hence, to be able to conduct an evaluation of IPS implementation in hospitals, it is necessary to gain knowledge about the stakeholder's ranking of evaluation criteria [11]. Therefore, our research question is which design criteria are relevant for IPS implementation projects in hospitals.

In order to address the research question, we apply two relevant frameworks. First, the "Project performance development framework" (PPDF) which has been successfully used to implement information systems [11] while being unclear regarding certain measures of a implementation project. Those measures are determined by applying the TOE framework that is appropriate for information systems implementation [8, 15] as the methodological guidance to the context of PPDF. Further, limitations of the TOE framework will be addressed by this study, as recent extensions of TOE framework suggest that measures for individual behavior should be used for TOE framework, such as "theory of reasoned action" or "theory of planned behavior" [8], despite TOE framework being a theory on an organizational-level [9, 15]. To that effect, this study provides propositions of hospital IT management and IPS developer towards design criteria for IPS implementation projects in hospitals on an organizational-level. Further and to improve future IPS research, the propositions are then applied to the evaluation of an IPS in a hospital setting by conducting a controlled experiment [16] leading to practical and theoretical implications of this study. The results contribute to health information system research by providing design criteria for IPS as well as the demonstration how the PPDF and TOE frameworks can be used in the domain for systems such as IPS.

The paper is organized as follows: In Section 4.2, we described the conceptual background of IPS which is followed by the depiction of the methodology (section 4.3) applied for deriving IPS design criteria. Section 4.4 contains the application scenario. The results are presented in Section 4.5 and discussed in Section 4.6. The paper concludes with Section 4.7 containing implications, limitations, and future research.

## 4.2 Conceptual background

An IPS ascertains the specific position of an individual or an asset due to an algorithm that processes certain signals (such as Bluetooth Low Energy (BLE) or Wireless-Fidelity (Wi-Fi)) [34, 55]. In this respect, the algorithm is based on different approaches to position determination, eg, by using the strongest signal (called Received Signal Strength Indication (RSSI)) or by measuring angles from phase differences of the signal. Further, IPS usually are either device- or monitor-based, whereas device-based IPS are often used for navigation and monitor-based IPS for tracking [55].

For IPS evaluation, Liu et al. [34] and Zafari [55] et al. determined relevant criteria. They are (i) accuracy (ii) availability, (iii) cost, (iv) energy efficiency, (v) latency/delay, (vi) precision, (vii) reception range, (viii) robustness, and (ix) scalability. In doing so, (i) accuracy of the IPS refers to the exactness of the location measurement, displayed in meters (m). (ii) Availability represents whether the IPS uses signals that can be processed by existing hardware (eg, smartphones) or extra hardware is required (eg, tags). (iii) cost should be low, as few or no additional hardware should be necessary for proper IPS operating. An IPS should respect (iv) energy efficiency by not draining device batteries. (v) Latency/delay concerning position determination of the IPS should be less than one second to ensure live localization. (vi) precision of the IPS describes the degree of fulfillment of the tasks that are set for the IPS. (vii) Reception range should be appropriate, as the signal emitted by the IPS should have a range of more than 10m. (viii) Robustness of the IPS should be as good as possible, eg, if a measuring point malfunctions, the IPS should be fundamentally functional nonetheless. Concerning (ix) scalability, an IPS should be tested with more than one device [34, 55].

As IPS have been subject of several studies [34, 55], various objectives for IPS in hospitals exist (see section 4.9) leading to respective functions the IPS have to perform. Further, case studies of companies in the IPS market provide functions for IPS in hospitals, such as Infsoft [25]. They are, but not limited to: navigating individuals [10]; treatment management [41]; compliance management [27]; warnings/alerts [26, 31, 32]; barrier-free navigation [55]; emergency calls [26]; monitoring care-intensive patients [49]; health care tracking [50]; parking management [25]; asset tracking [47]; inventory management [53]; indoor-outdoor navigation [3]; needs of older people (such as larger fonts)[5]; digital room and bed signage [24]; hospital communication [19]; push messages [19]; and augmented reality [22].

By considering IPS users, existing studies provide evidence regarding hospital employees [4, 50] and visitors [50]. As challenges for IPS, Zafari et al. [55] mainly state that operations conditions of IPS should be further investigated. Concretely, they refer to: the need of improving IPS algorithms to suppress multipath effects and noise (eg, as different radiations/magnetic waves in one building might influence IPS signals); the IPS environment and its special requirements (such as different radiations/magnetic waves in hospitals); and energy-efficiency, privacy and security, as well as cost concerns of IPS [55].

## 4.3 Methodology

### 4.3.1 PPDF and TOE framework

According to Barclay and Osei-Bryson [11] PPDF is a formal method that aims to develop a comprehensive set of performance criteria or objectives that are based on the views of stakeholders and to develop associated measures that are aligned to these objectives for projects. Among other projects, the PPDF was used to implement information systems [11]. The PPDF is particularly suitable to determine relevant performance criteria and objectives for IPS implementation in hospitals, as it considers iterative steps for the whole project lifecycle to determine what multiple stakeholders want of and from the project and to ascertain criteria therefore simultaneously [11]. Nonetheless, the PPDF itself is vague in regard to certain objectives and measures for implementing information systems (referring to "implementation of software in product environment" and "increased functionality of software in production environment" only while stating that "It is necessary to have the project measures reflective of the stakeholders' objectives to facilitate a consistent and effective evaluation process." [11]. Therefore, and to guide the research along the path of determining design criteria for IPS implementation projects in hospitals, the "Technology-Organization-Environment" (TOE) framework is applied to PPDF. The TOE framework is an organizational-level theory that states the adoption decisions of companies towards information systems are influenced by the technological context, the organizational context and the environmental context [15]. Thus, the contexts of the TOE frameworks are applied to the certain steps of PPDF, which are: (1) identify important stakeholders; (2) identify & structure project objectives; (3) elicit and define project measures; (4) prioritize project objectives.

### 4.3.2 Application to the context of implementing IPS in hospitals

We adopt the PPDF and TOE framework to the of context of implementing IPS in hospitals and describe how we designed the four steps for our research. First, stakeholders for IPS implementation in hospitals have to be determined [11]. Generally, TOE frameworks consider company representatives, software engineers and users as important stakeholders for IS implementation [9, 15] leading to the adoption of those stakeholder to the context of implementing IPS in hospitals. Second, objectives for the project have to be determined [11]. As we want to contribute to the scientific knowledgebase concerning IPS in hospitals and not to display a business use case concerning PPDF, we decided to guide the PPDF for IPS implementation in hospitals using the TOE framework. Thus, important stakeholders for our project are hospital IT management, IPS developer and users, as stated by TOE framework [9, 15]. Further, the TOE framework also specifies objectives for IPS implementation projects in hospitals, as propositions have to address technological, organizational and environmental contexts [9, 15]. Third, measures have to been designed to verify the project objectives [11]. As PPDF was used to implement IS as an objective, Barclay and Osei-Bryson recommend to implement the IS in product environment and to test its functionality as measures concerning PPDF [11]. In regard to TOE framework, the measures concerning the implementation and functionality testing have to address technological, organizational and environmental contexts as well. Fourth and finally, the project objectives have to be prioritized [11]. This leads, combined with the TOE framework, to a weighted importance of technological, organizational and environmental contexts [9, 11, 15]. Thus, our integrated PPDF-TOE-Framework is presented in Figure 18.

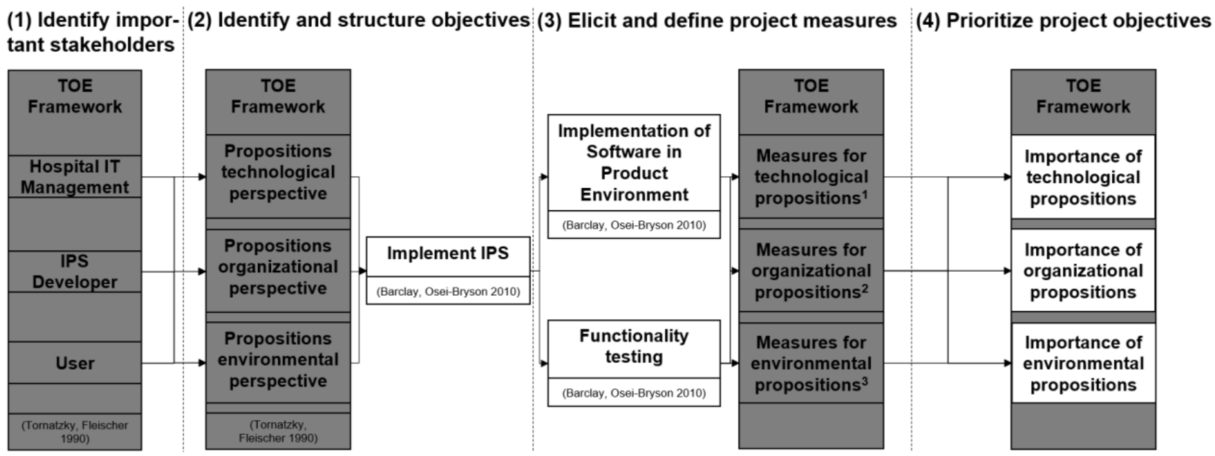


*Figure 18: Procedure for identifying design criteria for IPS in hospitals based on Barclay and Osei-Bryson [11].*

## 4.4 Application Scenario for identifying design criteria for IPS in hospitals

In order to apply the integrated PPDF-TOE-Framework to IPS, we propose an application scenario for our study and present certain measures that can be used to determine design criteria for IPS implementation projects in hospitals. First, important stakeholders have to be identified [11], which are hospital IT management, IPS developer and user, according to TOE framework [9, 15]. Since recent extensions of TOE framework recommend to use quantitative measures to ascertain individual behaviors [8], users were excluded from the stakeholder party of our research, since their requirements towards IPS for both, hospital employees [4, 50] and hospital visitors [50] have already been investigated with such quantitative measures. Second, objectives for the project have to be determined. As Zafari et al. [55] referred to many functions an IPS should have while also stating that costs are a critical barrier to implementing IPS in hospitals, a cost-benefit analysis concerning IPS functions for hospitals from the perspective of hospital IT management and the IPS developer (that also addresses at least the organizational context of TOE framework [15]) would be beneficial to encounter important paradigms of information systems development [18] for IPS [55]. This leads to the first objective of the study: "conduct a cost-beneficial analysis of IPS functions in hospitals". Further, [34, 55] proposed evaluation criteria that are currently of equal weight, which is, considering the important paradigms of information systems development [18], not beneficial. Therefore, our second objective is to “obtain weighted IPS evaluation criteria”, which would contribute to the technological context, according to DePietro et al. [15] and Baker [9]. Furthermore, Zafari et al. state that “Indoor localization is highly dependent on the characteristics of the indoor environment.” [55] leading to the need to “gain knowledge about sufficient IPS operations conditions in hospitals”, which would at least be beneficial to the environmental context of TOE, according to DePietro et al. [15] and Baker [9]. Our application scenario is described in Figure 19.

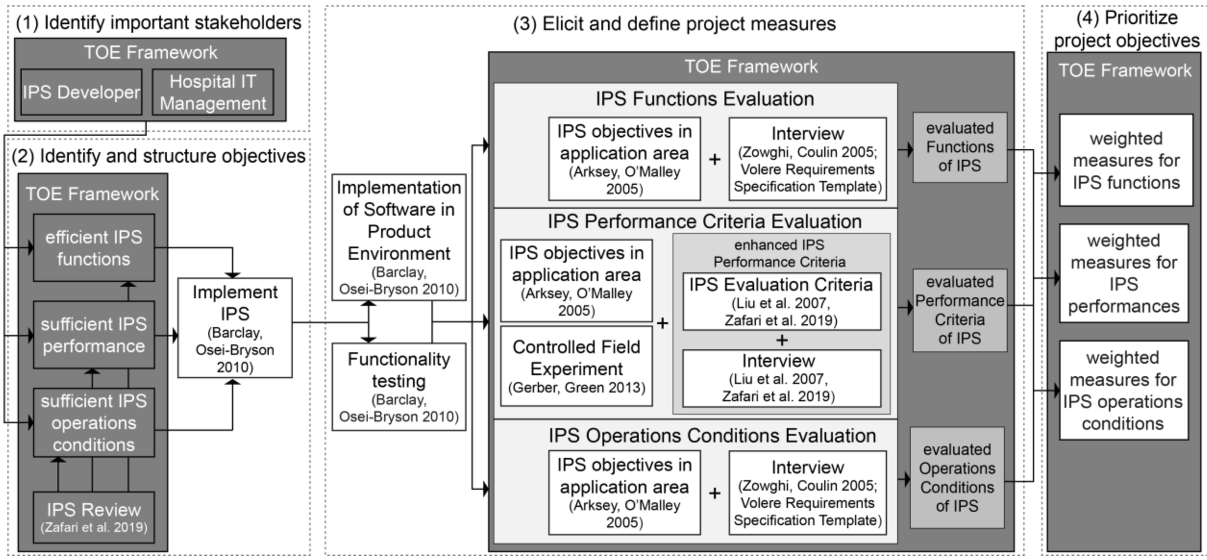


*Figure 19: Application scenario for identifying design criteria for IPS in hospitals based on Barclay and Osei-Bryson [11].*

As shown in Figure 19 and according to our TOE framework objectives, certain measures are necessary to ascertain the objectives. According to PPDF, the measures to implement an IS are: to implement the IS in product environment and to test its functionality [11]. Combined with our TOE framed objectives, we specified certain measures for IPS evaluation [6, 7, 16, 34, 55, 56].

To gain knowledge about IPS functions, evaluation criteria and operations conditions for/in hospitals, we screened scientific literature databases (Scopus, AISeL, IEEE) and IPS companies websites (such as Infsoft [25]) following the recommendations of Arksey and O’Malley [6]. Furthermore, we conducted CFEs according to Gerber and Green [16] using an ultrasound-based IPS (as this type of IPS is quite precise according to Zafari et al. [55]) on two floors of a university building. During the experiments, we tested two different scenarios with loudspeakers (see “references nodes” in Zafari et al. [55]). First, we used seven speakers to determine the position. Second, we disabled three of them (see Figure 20). For position determination, we used acoustic signals from loudspeakers and fingerprinted their RSSI (see Liu et al. [34] and Zafari et al. [55]) as the localization technique. The fingerprinting is divided in two phases: an online phase in which fingerprinting mapping data that was collected with a Huawei smartphone by traveling the hallways for each floor (ie, 8 times in total) and the offline phase, were the validation is realized. In the offline phase, the relative cross correlation data (as the relevant IPS signal) is stored together with the position data that is acquired by the RPLidar 3 and Intel Camera T265 (see Figure 20). During the experiments, the cross correlation is performed between the audio data that is recorded by the smartphone and (currently) 27 IPS reference signals. Then, a vector is constructed from those 27 reference signals and 3 X-, Y- and Z-positions are stored as fingerprint mapping data. Accordingly, the IPS requires pre-measured premises (eg, via digital building maps) for proper functioning. In the online phase, the cross correlation between the audio signals recorded by the smartphone and the 27 reference IPS signals is performed. Then, a "k Nearest Neighbor" (k = 1) algorithm (see Zafari et al. [55]) is used to determine the k IPS positions that are nearest in terms of fingerprint to the currently recorded audio. Further, weighting is applied to the k IPS signals to receive weighted IPS signal results and to improve IPS accuracy [55]. The experimental setup is similar to Rozum et al. [42].

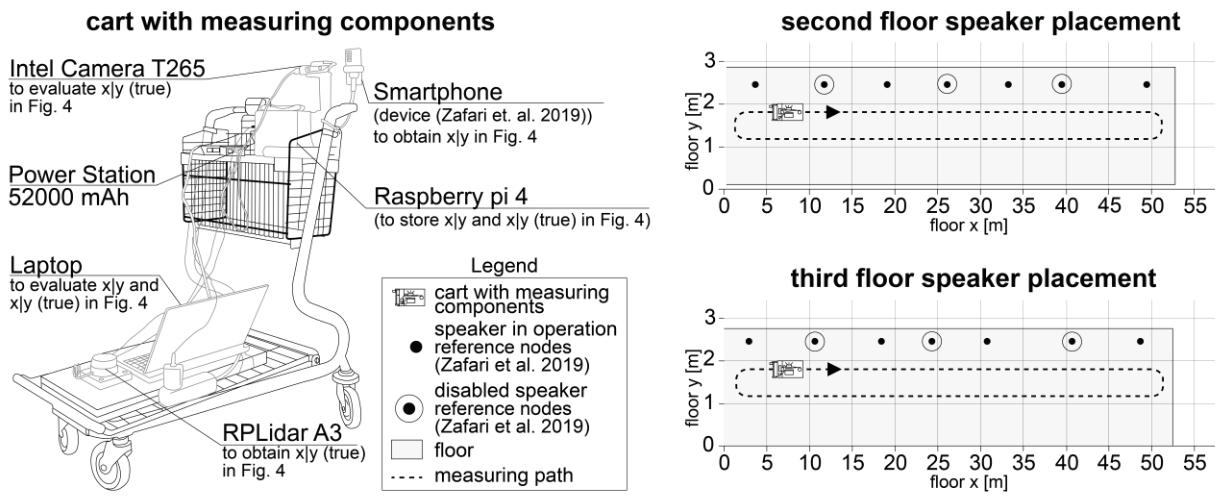


*Figure 20: Experimental setup ultrasound-based IPS.*

For the experiments, the commonly used devices LG G8S ThinQ, HUAWEI Mate 8 and Sony Xperia X Compact with different build-in loudspeakers were used.

## 4.5 Results

We conducted interviews with 5 IPS developers from different companies and 5 representatives of hospital IT management from different hospitals and refer to them as "experts" in the ongoing section.

In terms of functions, all experts believe that individuals should be navigated and most experts that assets should be tracked using IPS, with the following functions having a good cost-benefit ratio in terms of most experts: a warning/alert function [26, 31], a function for barrier-free navigation that also takes visually impaired people into account [55], an emergency call function [26] and functions that are specially adapted to the needs of older people (such as larger fonts) [5]. Further, the IPS should allow push messages [19]. Integrating Corona-tracing functions [50] was deemed less important by all experts.

Concerning the IPS evaluation criteria, we asked our experts to rank among them to gain enhanced IPS performance criteria. Most of the experts agreed that (i) accuracy and (ii) availability are more important and (iv) energy efficiency and (ix) scalability are less important evaluation criteria while assessing (vi) precision separately (as more important by the IPS developer and disputed by the hospital IT management). (iii) cost, (v) latency/delay, (vii) reception range and (viii) robustness are disputed. Further, our experts recommended considering (iii) cost and (ix) scalability in more detail. Therefore, they recommended investigating (iii) cost concerning (iii.1) additional hardware and (iii.2) their IPS localization technique (such as Fingerprinting, RSSI) as described by Zafari et al. [55]. (ix) scalability should not only be considered by using multiple devices (as (ix.1)) but by using different operating systems (as (ix.2)) as well. Accordingly, we used the enhanced IPS performance criteria to report on IPS performances in controlled experiments and to evaluate those IPS in hospitals, we have obtained through our literature analysis.

The CFEs [16] were conducted with 3 different smartphones on two different floors. As disabling three loudspeakers led to IPS failure, we are not able to provide results therefore. In the ongoing, the results for all seven speakers are described, beginning with IPS accuracy in Figure 21.

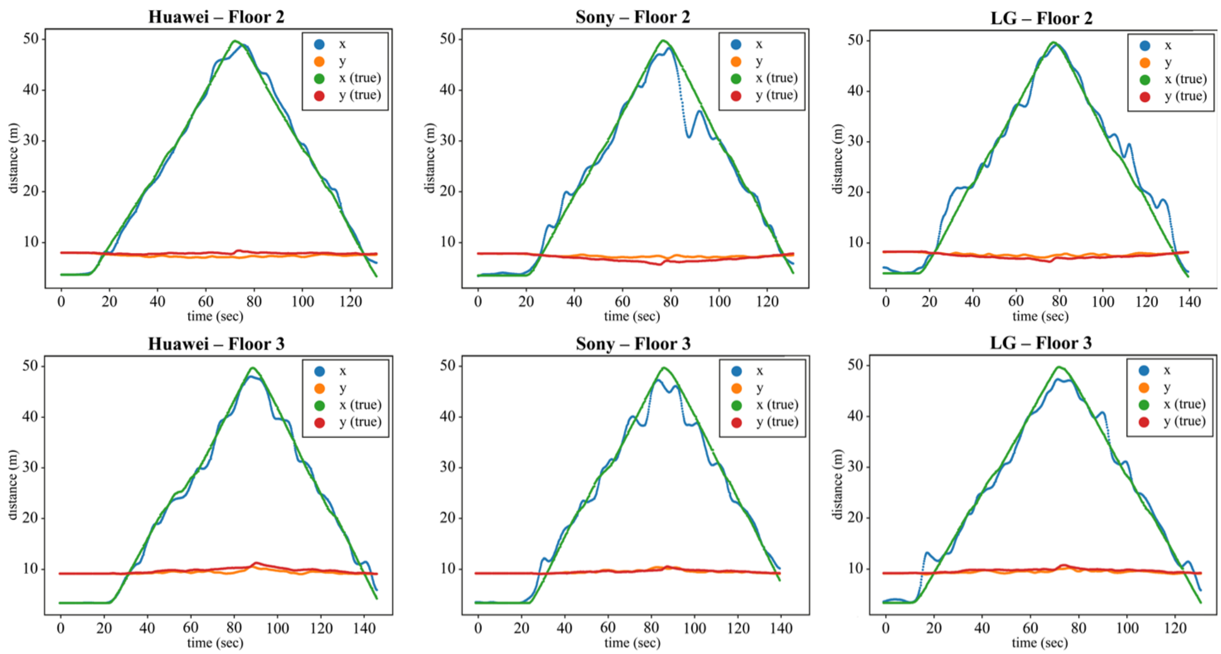


*Figure 21: Experimental results ultrasound-based IPS.*

The green and red lines represent the actual distance that is ascertained by the Intel camera T265 in Figure 20. The blue and orange lines describe the signals measured by the respective smartphones. The descriptives for Figure 21 are presented in Table 6. Thereby, RMSE is the "root mean square error", representing the standard deviation to the actual position measured by the tracking camera. Thus, x accuracy refers to the length of the floor and y accuracy to the width, respectively. As two floors with speakers were considered, the accuracy percentage concerning the correct prediction of the respective floor over the total distance covered was also measured. Additionally, the overall performance of the experiment was determined.

*Table 6: Descriptives concerning experimental results ultrasound-based IPS.*

| Floor | Device | Experiment No. | Total Distance Covered | Filtering Type | X Accuracy | Y Accuracy | RMSE (X, Y) | Floor Accuracy Percentage |
|---|---|---|---|---|---|---|---|---|
| 2nd | Huawei | 1 | 93.8m | RSSI (no filter) | 1.67m | 0.8m | 2.01m | 99.2% |
| | | | | Gaussian | 0.75m | 0.8m | 1.18m | 100% |
| | | 2 | 93.9m | RSSI | 1.53m | 0.48m | 1.72m | 98.6% |
| | | | | Gaussian | 0.8m | 0.46m | 1.0m | 100% |
| | Sony | 3 | 94.8m | RSSI | 2.38m | 0.48m | 2.54m | 96.3% |
| | | | | Gaussian | 1.4m | 0.45m | 1.54m | 100% |
| | LG | 4 | 94.1m | RSSI | 2.28m | 0.37m | 2.37m | 95.99% |
| | | | | Gaussian | 1.14m | 0.14m | 1.17m | 100% |
| | | 5 | 94.0m | RSSI | 2.59m | 0.39m | 2.7m | 95.4% |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Gaussian | 1.58m | 0.35m | 1.69m | 100% |
| 3rd | Huawei | 6 | 97.34m | RSSI | 1.24m | 0.43m | 1.43m | 99.35% |
| | | | | Gaussian | 0.61m | 0.39m | 0.79m | 100% |
| | | 7 | 98.8m | RSSI | 1.47m | 0.38m | 1.63m | 99.35% |
| | | | | Gaussian | 0.85m | 0.34m | 0.97m | 100% |
| | Sony | 8 | 98.65m | RSSI | 2.3m | 0.44m | 2.44m | 96.47% |
| | | | | Gaussian | 1.5m | 0.42m | 1.63m | 100% |
| | | 9 | 97.95m | RSSI | 2.15m | 0.35m | 2.23m | 97.56% |
| | | | | Gaussian | 1.34m | 0.12m | 1.36m | 97.95% |
| | LG | 10 | 98.3m | RSSI | 2.02m | 0.37m | 2.14m | 97.96% |
| | | | | Gaussian | 1.22m | 0.25m | 1.29m | 100% |
| | | 11 | 97.44m | RSSI | 2.23m | 0.39m | 2.34m | 97.4% |
| | | | | Gaussian | 1.35m | 0.26m | 1.41m | 100% |
| overall | | | | RSSI | 2.46m | 0.45m | 2.6m | 95.62% |
| | | | | Gaussian | 1.57m | 0.35m | 1.69m | 99.90% |

Further, we evaluated our experiments using the enhanced evaluation criteria for IPS. Concerning (i), we achieved an overall accuracy of 1.69m using Gaussian filters. As we used ultrasonic audio for position determination that is processible by various smartphones, (ii) availability is good. Nonetheless, loudspeakers are necessary to emit ultrasonic audio for position determination that are not always part of existing infrastructure, resulting in high (iii.1) cost of the IPS. Further (iii.2) cost are high, since fingerprinting is used to ascertain the position, as stated by Zafari et al. [55]. (iv) energy efficiency is not applicable, as our experiment is not a mature IPS. The transmission of the ultrasound audio is latency-free, as it is issued continuously, resulting in low (v) latency/delay. Regarding (vi) precision, the task for the IPS was to identify the correct floor, which was succeeded for 99.9% of the experiments' distances. (vii) reception range is low, as the loudspeakers were placed less than 10 meters from each other (see Figure 20). (viii) robustness is determined poor, as blocking the microphone of the smartphone (eg, by having a phone call or by carrying the smartphone in the pocket) leads to excessive decreases concerning (i) accuracy. As we used different smartphones for the experiments, (ix.1) scalability is high, but all of them were Android-based, resulting in a low (ix.2) scalability. Table 7 provides an overview on our results regarding the criteria compared to other studies identified in the literature.

*Table 7: Enhanced Evaluation of IPS in hospitals.*

| (References) | Techno-logy | + more important + | | | +/- disputed +/- | | | | | - less important - | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (i) | (ii) | (vi) | (iii.1) | (iii.2) | (v) | (vii) | (viii) | (iv) | (ix.1) | (ix.2) |
| Our experiment | Ultrasonic audio | 1.69 m | good | 99.9% | high | high | low | low | poor | N/A | high | low |
| Aoki et al. [5] | Wi-Fi | N/A | poor | 93.3% | low | high | N/A | N/A | poor | low | low | low |
| Bao et al. [10] | Wi-Fi | 2.31m | good | 88% | low | high | low | good | poor | N/A | high | low |
| Chriki et al. [13] | Wi-Fi | N/A | good | 88.38% | low | high | high | good | N/A | N/A | N/A | low |
| Gouin-Vallerand and Rousseau [17] | Wi-Fi | 2.20-4.49m | good | 82% | high | low | high | poor | N/A | N/A | high | high |
| Lu et al. [35] | Wi-Fi | 3.73m | good | 94.25% | low | high | N/A | good | good | high | low | low |
| Mathisen et al. [37] | Wi-Fi | 2.95m | good | 95.78% | low | low | high | good | poor | N/A | high | low |
| Stisen et al. [46] | Wi-Fi | N/A | good | 89.2% | low | low | high | good | poor | high | N/A | N/A |
| Wille et al. [52] | Wi-Fi | N/A | good | N/A | low | high | high | N/A | poor | low | high | high |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Yogaprakash and Soh [53] | Wi-Fi | 2.54m | good | 72% | high | high | N/A | good | poor | high | N/A | N/A |
| Kanan and Elhassan [26] | Wi-Fi + Radio frequency identification (RFID) | 2-3m | good | N/A | high | high | low | good | N/A | high | high | N/A |
| Hou et al. [20] | Wi-Fi | 2.5m | good | N/A | high | high | high | good | N/A | high | low | low |
| van Haute et al. [48] | Wi-Fi + BLE + ZigBee | Wi-Fi: 2.68m BLE: 3.12m ZigBee: 3.08m | good | Wi-Fi: 46.58% BLE: 61.64% ZigBee: 49.32% | high | high | N/A | good | good | high | low | N/A |
| Anagnostopoulos and Deriaz (2014) [2] | BLE | .97m | good | N/A | low | low | high | poor | N/A | high | high | high |
| Anagnostopoulos and Deriaz (2015) [3] | BLE | 5-14.99m | good | N/A | low | low | high | poor | poor | low | high | N/A |
| Chu et al. [14] | BLE | 3-5m | good | 82% | high | low | low | poor | N/A | high | high | low |
| Ho et al. [19] | BLE | 1.48m | good | N/A | high | high | high | poor | poor | N/A | low | N/A |
| Huang et al. [22] | BLE | 3-5m | good | N/A | high | low | high | poor | N/A | low | high | low |
| Ku et al. [29] | BLE | N/A | good | 88.24% | high | low | N/A | good | poor | N/A | low | N/A |
| Li et al. [32] | BLE | 1.29m | good | N/A | high | low | N/A | poor | N/A | N/A | low | high |
| Lin et al. [33] | BLE | 3-5m | good | 97.22% | high | low | high | poor | poor | high | low | N/A |
| Nguyen et al. [38] | BLE | 0.125-0.37m | good | N/A | high | low | N/A | poor | N/A | high | low | high |
| Ramezani et al. [39] | BLE | N/A | good | N/A | high | low | low | N/A | N/A | high | high | N/A |
| Roy et al. [41] | BLE | N/A | good | 92% | high | high | low | good | N/A | high | high | low |
| Shipkovenski et al. [43] | BLE | N/A | good | N/A | high | high | N/A | poor | N/A | high | N/A | N/A |
| Yoo et al. [54] | BLE | 5.48m | good | 67.4% | high | high | N/A | N/A | N/A | N/A | high | low |
| Karimpour et al. [27] | BLE | N/A | good | 92% | high | low | high | poor | N/A | N/A | low | N/A |
| Rozum et al. [42] | BLE | 0.92m | good | N/A | high | N/A | high | good | poor | N/A | N/A | N/A |
| van der Ham et al. [47] | BLE | 0.5m | good | 70% | high | high | N/A | N/A | poor | N/A | N/A | N/A |
| Marini et al. [36] | BLE | N/A | good | N/A | high | low | high | poor | N/A | N/A | high | N/A |
| van Woensel et al. [49] | BLE | N/A | good | 87.70% | high | low | high | good | good | high | N/A | high |
| Aguilar-Garcia et al. [1] | RFID | 1-2m | poor | N/A | high | high | low | poor | good | low | high | low |
| Calderoni et al. [12] | RFID | N/A | poor | 83% | high | high | N/A | good | poor | low | high | N/A |
| Lee et al. [31] | RFID | N/A | poor | N/A | high | high | N/A | poor | N/A | N/A | N/A | N/A |
| Silva et al. [44] | RFID | N/A | poor | N/A | high | low | N/A | good | N/A | low | high | N/A |
| Steele et al. [45] | RFID | N/A | poor | 86.58% | high | N/A | N/A | good | poor | N/A | high | N/A |
| Hsiao et al. [21] | ZigBee | 2.3m | poor | N/A | high | high | N/A | good | N/A | low | high | N/A |
| Romme et al. [40] | Ultra-wideband | 0.87m | poor | N/A | high | high | low | poor | N/A | N/A | low | N/A |
| Konecny et al. [28] | Infrared | N/A | poor | N/A | high | N/A | low | poor | N/A | low | high | N/A |

Regarding operations conditions of IPS in hospitals, our experts stated that IPS signal could be influenced by radiations/magnetic waves and metallic shields, often particularly relevant in hospital departments such as radiology, radiotherapy, and nuclear medicine. Basically, our experts argued that requirements for IPS in hospitals should be gathered and applied to IPS implementation projects as early and comprehensively as possible (eg, with regard to possible structural changes, maintenance cycles as well as the power supply of the IPS, for which power-over-ethernet should be checked). Further, they argue that generating personal data by the IPS should be avoided as much as possible. If they still have to be generated, a high security standard (eg, AES-256) should be used. To comply with legal regulations (eg, the EU-GPDR), the IPS servers should be operated in the same country as the IPS in the hospital. The support of the IPS should be online and remote and be based on both technical (eg, help with app crashes) and content (eg, missing representations of rooms) related issues. Concerning scalability, our experts recommend to consider the most important smartphone operating systems (such as Android, iOS) and web applications as platforms for the IPS. Further, the IPS should be cloud-based, backward compatible (eg, by being usable for smartphones being issued within the last five years) and using responsive designs. In accordance to the implementation of the IPS, intensive testing of the system should be carried out (eg, crowd testing, friendly user trial). The hospital should also inform its users (patients and hospital staff) about the use of the app.

Concerning (4) prioritize project objectives of the PPDF-TOE-framework, our experts agree that IPS operations conditions are less important compared to IPS functions and IPS evaluation criteria, with no discernible ranking between the latter.

## 4.6 Discussion

Regarding IPS functions in a cost-benefit analysis scenario, our results illustrate that, compared to the functions presented in the conceptual background, only a few of these functions were judged positively by our experts in terms of a cost-benefit ratio. Combined with the new evidence regarding the assessment of the (iii) cost of an IPS, as well as the avoidance of personal data to the greatest extent possible, it is likely that many functions were not considered because at least one of these arguments was true. These include: treatment management [41]; compliance management [27]; monitoring care-intensive patients [49]; parking management [25]; inventory management [53]; indoor-outdoor navigation [3]; digital room and bed signage [24]; hospital communication [19]; and augmented reality [22].

Concerning the evaluation criteria for IPS, our results reflect that (i) accuracy and (ii) availability are more important and we thereby confirm the propositions of Zafari et al. [55] who stated that accuracy and availability are fundamental requirements of indoor localization. In contrast to Zafari et al. [55], our experts deemed energy efficiency as “less important”, thereby counteracting the proposition of Zafari et al. [55] that highly accurate localization that is provided in real-time might drain batteries of user devices as well as reference nodes (such as routers). The contrary propositions are probably related to the facts that on one side, the user devices are not of primary importance to our experts and, on the other side, our experts rely on a power-over-ethernet connection instead of batteries for reference nodes, which has already been adopted by some companies in the IPS market [23]. Further, our experts confirm the propositions of Zafari et al. [55] in that scalability is less important for device based localization. It was likely to happen that (vi) precision was evaluated differently by our experts, since it provides information about the functions of the IPS, which in turn allow conclusions to be drawn regarding the necessary complexity of the systems to enable the functions [34]. Thus, it is likely that the (vi) precision (and the resulting functions of the IPS) make it easier for the IPS developer to design the right IPS for the hospital in question [34], since eg, user requirements are available [4, 50] that lead to certain functions for IPS [11, 15].

As for our controlled experiments, we performed quite well in terms of (i) accuracy, (ii) availability, (v) latency/delay, (vi) precision and (ix.1) scalability, while poorly performed in (iii.1 and 2) cost, (vii) reception range, (viii) robustness, and (ix.2) scalability compared to the IPS in Table 7. To encounter high (iii.1) cost, Zafari et al. [55] recommend to avoid additional hardware, which is not suitable for our approach, as additional references nodes (such as speakers) are needed to emit acoustic signals [55]. As for Zafari et al. [55], only mere RSSI values could reduce the (iii.2) cost, compared to fingerprinting approach. Thus, with our current algorithm, lowering (iii.2) cost would decrease (i) accuracy. Nonetheless, we have to improve our IPS algorithm to increase (viii) robustness [34] and to test it using different operating systems (eg, iOS) to address (ix.2) scalability, as stated by our experts.

Regarding the operations conditions for IPS in hospitals, our results support the proposition of Zafari et al. [55] that IPS are indeed highly dependent on the characteristics of the indoor environment, with our experts referring to characteristics of hospitals. Further, our results support cloud-based IPS that Zafari et al. [55] considers for high processing power and continuous power supply and emphasize that compliance with applicable data policies, especially with respect to personal data, is very important, as also noted by Zafari et al. [55].

## 4.7 Conclusion

This study addresses the determination of design criteria for indoor positioning system implementations using PPDF and TOE as the underlying frameworks. Thereby, sufficiently measured and weighted design criteria were determined in the form of IPS functions, IPS evaluation criteria and IPS operations conditions in hospitals, answering the research question posed at the beginning. Concerning the controlled experiments, we conclude that our algorithm is sufficient for IPS purposes, as it completed the task of floor prediction sufficiently by being comparably accurate despite using several smartphones. Nonetheless, our algorithm is not yet error-prone and has to be further investigated in terms of robustness.

On a theoretical level, our implications for healthcare information systems research are as follows. First, we provide an integrated PPDF-TOE framework applied on IPS in hospitals which demonstrates how design criteria can be assigned to such a system. Our insights show that both frameworks can be applied together in a meaningful way which can also be applied to different types of information systems in hospitals to derive their design criteria. Second, by applying the TOE framework to PPDF we add comprehensible measures to the rather vague measures of PPDF for the objective to implement an IPS. Third, our empirical insights contribute to understanding the organizational level of the TOE framework for IPS better. Fourth, we enhanced cost and scalability as evaluation criteria for IPS that should be included in the evaluation of other types of IPS.

On a practical level, we provide enhanced IPS evaluation criteria that hospitals can use to evaluate their IPS. Further, we provide several IPS functions and operations conditions for IPS in hospitals other hospitals can use to evaluate their IPS functions and operations conditions. Likewise, IPS developer benefit from this study by obtaining useful insights of other IPS developers as well as hospital IT management as their potential customers, which they can use to improve IPS development.

As any research, our study is subject to limitations. Our number of experts is relatively small (with 10 individuals), thus our findings can be considered as variables of quantitative investigations of the experts to be verified. However, it is difficult to build a corresponding peer group for quantitative investigations consisting of IPS developers and representatives of hospital IT management, since these experts are represented in significantly smaller numbers worldwide than eg, users. Furthermore, our conclusions are limited by the fact that our identified IPS functions have so far only been evaluated from a cost-benefit perspective by representatives of hospital IT management and IPS developers. Future research could therefore evaluate the actual functionality of our determined IPS functions from the user's perspective. Regarding our controlled experiments, further investigations could be carried out that focus on the signal processing of our algorithm to increase reception range and the overall error-proneness of the algorithm to improve robustness and to ensure sufficient operation even if three speakers (= reference nodes) are disabled.

## 4.8 References


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## 4.9 Appendix

### Objectives for IPS in hospitals

All of the IPS either considered the tracking and navigation of / to people or devices or the tracking of patients / workers exercising tasks to determine behavioral patterns as the main objective of their study, with some research tackling more granular issues that are represented by a “+”.

| **Objectives** | **References** |
|---|---|
| tracking and navigation of / to people or devices | [1, 2, 5, 11, 27, 29] |
| +indoor- and outdoor IPS | [3, 9] |
| +to ensure compliance measures | [15] |
| +to prevent stealing of assets | [34] |
| +to manage emergency situations | [14, 18, 38] |
| +to prevent kidnapping of newborns | [17, 19] |
| +to dissolve overcrowded emergency departments | [10] |
| +to design a patient-centered smart hospital | [40] |
| +to design a navigation system dedicated to elderlies | [4] |
| +to design an augmented reality-based IPS | [13] |
| +to access control, to generate real-time system alarm | [31] |
| +to direct virtual care | [36] |
| +to track hospital beds | [7, 20, 21, 25] |
| +to develop a waypoint-based indoor navigation system | [8] |
| +to use heuristics / clustering in tracking | [6, 28, 30, 35, 39] |
| +to design an IPS for urgent care | [16] |
| +to compare different IPS technologies | [24] |
| tracking of patients / workers exercising tasks to determine behavioral patterns | [12, 22, 23, 26, 32, 33] |