Design and Modeling in Pervasive Information Systems

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1 Introduction

The previous chapter highlighted the different requirements that a pervasive information system should fulfill, namely Context-awareness, Managing heterogeneity, Transparency, Fulfillment of the requirements and Adaptation.

Despite the numerous works in the pervasive information systems domain, works specifically aiming at its design or modeling seem to be neglected. We decided to study the literature in order to be able to draw some conclusions about this statement. We made a systematic mapping review, specifically addressing design methodology and modelling techniques in pervasive information systems and analyzed the results to draw a panorama of modeling in PIS.

To our knowledge, there is only one existing review about modeling issues in pervasive information systems. In (Ng and Wakenshaw 2017), the authors present four conceptualizations of IoT from the following theoretical constructs: liquification and density of information resources; digital materiality; assemblage and service system; and modularity and transaction network. The paper presents the conceptualizations and implications of IoT, specifically addressing marketing issues. However, this review doesn't give any information on the PIS requirements fulfillments.

According to the PIS vision developed in the first chapter of the book, we would like to see how the requirements are fulfilled in the existing sources in the literature. We also want to know if they either apply traditional design methodology, adapt an existing one or develop a new one for integrating the pervasive aspects in the IS.

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The remaining of this chapter is organized as follows: Sect. 2 explain the SMS research methodology used in this work, while Sect. 3 analyze the results, before concluding on Sect. 4.

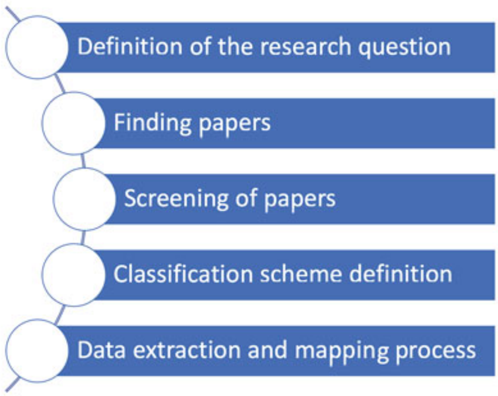
2 Research Approach

We used a systematic mapping design (Petersen et al. 2008) to study the field of research. Systematic Mapping Studies (SMS) are similar to other systematic reviews, except that they employ broader inclusion criteria to select a wider range of research papers and are intended to map out topics with field classification rather than synthesize study results. The study presented here covers the existing work in the field of design methodologies and modeling techniques in pervasive information systems. We followed the process presented in (Petersen et al. 2008) which includes five steps: definition of research questions, conducting search for primary studies, screening of papers, keywording of abstract and data extraction and mapping of studies. Based on (Petersen et al. 2008), we followed the procedure on SMS. We named differently the Steps 2 and 4 as more compliant with our research process (see Fig. 1).

Step 1: Definition of Research Questions
The main goals of this SMS are to define:

- *RQ1*. What is the distribution evolution of the sources?
- *RQ2*. How is addressed the design and modeling of pervasive information systems in research proposals (which strategies are applied in design-dedicated research proposals)?
- *RQ3*. How are met the PIS requirements presented in the first chapter of the book in these design-dedicated research proposals?

Fig. 1 Research process



Step 2: Finding Papers This step aims at identifying a set of papers based on a relevant search string. We searched and selected papers in the SCOPUS scientific database using the SCOPUS Search API. We restricted our search to sources published after 2015. To identify all existing works about design-dedicated research proposals, we used the keywords Design (we search design proposals), Method (these proposals can address methodology issues) and Model (these works can define models or modeling techniques). As we focus on PIS, we used the keywords Information System and Pervasive, but also IoT (pervasive systems often use IoT technologies) and Service (these IS may be defined as service oriented). Our search string was then the following: *(TITLE-ABS-KEY(IoT) or TITLE-ABS-KEY(pervasive)) and (TITLE-ABS-KEY(model) or TITLE-ABS-KEY(method) or TITLE-ABS-KEY(design)) and TITLE-ABS-KEY(service) and TITLE-ABS-KEY("information system") AND PUBYEAR > 2015*. We obtained 333 sources with DOIs. The inclusion criterion related to the search string is given in Table 1.

Step 3: Screening of Papers We analyzed the titles and, if needed the abstract and the papers content, to exclude 288 sources, not representing a research paper or not relevant to modelling in pervasive information systems. We obtained 45 papers. In Table 1 we summarize the exclusion criteria used to obtain the list of relevant papers.

Step 4: Classification Scheme Definition The goal of this step of SMS is to identify the classification scheme to be applied to the obtained results. To answer the defined research questions, we classified all relevant papers accordingly to the

Table 1 Inclusion/exclusion criteria for the study on Smart Topics

Selection criteria	Criteria description
Inclusion criteria (333 sources identified)	The paper contains a set of terms like "IoT" or "Pervasive", concerns either "model" or "method" or "design", "service" and "information system". The paper is published after 2015. From the abstract it is clear that a contribution towards modeling on pervasive system is made. Search string: (TITLE-ABS-KEY(IoT) or TITLE-ABS-KEY(pervasive)) and (TITLE-ABS-KEY(model) or TITLE-ABS-KEY(method) or TITLE-ABS-KEY(design)) and TITLE-ABS-KEY(service) and TITLE-ABS-KEY("information system") AND PUBYEAR >2015
Exclusion criteria	The source is not a research paper (erratum, retracted, etc.).
(TTT sources selected)	The source is not in English or in French. The source is secondary. The source does not concern modelling in pervasive information systems.

Table 2 Classification criteria

Selection criteria	Criteria description
Criteria related to publication evolution	Year Type of venues
Criteria related to the proposal	Type Nature Added value Usage of the IoT based system Application domain
Criteria related to PIS requirements	Context awareness Managing heterogeneity Transparency Fulfillment of the requirements Adaptation

criteria detailed in Table 2. For RQ2 (strategies applied to build PIS), we studied several criteria: the nature of the proposal, its added value, the usage of the IoT system and its application domain.

Step 5: Data Extraction and Mapping Process For RQ1, we studied the publication year and issue to identify the publications evolution, tried to identify which of the PIS requirements stated in chapter "What Is a "Pervasive Information System" (PIS)?" were fulfilled by the selected papers. For the cloud we deleted the stop words, the numbers, and the special characters. For RQ2, we looked deeper into the papers to identify the exact type, nature, added value and usage of the proposal. We used an existing taxonomy of smart life applications to identify the scope of the diverse applications domains of the selected papers. For RQ3, we identified if the proposal was fulfilling the PIS requirements defined in chapter "What Is a "Pervasive Information System" (PIS)?".

Validity Threats Qualitative research is based on subjective, interpretive, and contextual data. Thus, we analyzed the potential biases, which could threaten the validity of our research. (Thomson 2011) proposes five categories of validity. To minimize the impact of the validity threats that could affect our study, we present them with the corresponding mitigation actions in Table 3.

3 Results of the Systematic Mapping Study

In this section, we sum up the results obtained during our SMS. Very few papers are really concerned about design and modelling in pervasive information systems.

Table 3 Validity threats

Validity	Actions
Descriptive validity refers to the accuracy of the data	We unified the concepts and criteria used in the study and structured the information to be collected with a data extraction form to support a uniform recording of data.
Theoretical validity depends on the ability to get the information that it is intended to capture.	We used a search string and applied it on a library including the most popular digital libraries on computer sciences and software engineering. A set of inclusion and exclusion criteria have been defined. We combined two different search methods: an automatic search and a manual search (backward and forward snowballing), to diminish the risk of not finding all the available evidence. The choice of English and French sources should be of minimal impact concerning the discard of other languages.
Generalization validity is concerned with the ability to generalize the results.	Our set of research questions is general enough to identify and classify the findings on modelling on pervasive systems.
Evaluative validity is achieved when the conclusions are reasonable given the data.	Two researchers studied the papers, working independently but with an overlap of studies to identify potential analysis differences. At least two researchers validated every conclusion.
Transparency validity refers to the repeatability of the research protocol.	The research process protocol is detailed enough to ensure it can be exhaustively repeated.

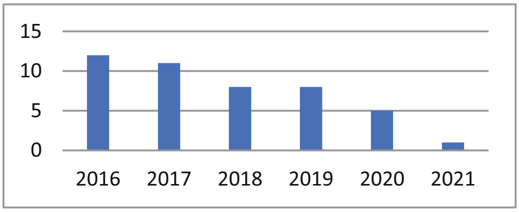


Fig. 2 Growth of the number of papers on modelling on pervasive information systems

3.1 RQ1. What Is the Distribution Evolution of the Sources?

We studied the evolution of the sources through time and publication venues. We also looked at word frequencies in the papers metadata (titles, abstract and keywords).

Distribution over time Figure 2 shows the appearance of the papers on our topic through time.

Designing a PIS is not an area that is widely studied and we can even see a decreasing of the number of papers allocated to this specific notion over time. It is known for a long time that design and modeling is an important part of an information system development. In (Borgida 1986), the authors state that modeling

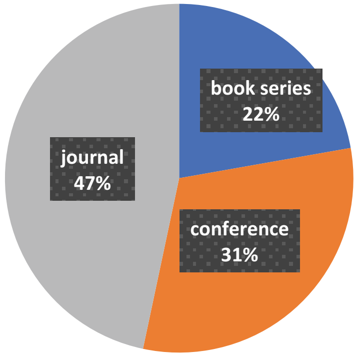


Fig. 3 Papers distribution by publication type

allows to develop information systems in an easier way because of focusing on the application domains semantics. However, here as in most proposals, the need for conceptual schemas in the development of information systems is often overlooked or simply disregarded (Olivé 2007).

Sources of Papers Publishing on Design and Modelling on Pervasive Systems One of our goals is to analyze the venues of papers publishing on this specific topic. This question leads us to study the distribution of publications by type of venue: conferences, journals, or workshops, resulting on the distribution presented in Fig. 3. Half of the papers are journal papers, a quarter are conference ones and the other quarter are papers in book series. There is a quite a good distribution of publication issues and there is no specific issue which can be identified as ‘the’ issue to publish on modeling in PIS.

Cloud words We used the titles, abstracts and keywords of the selected papers to look about word frequencies. We deleted the stop words, the numbers, and the special characters. Moreover, we made a pre-processing of the data to change plural nouns into singular ones if the two forms were present in the dataset. We created a word cloud (see Fig. 4) to illustrate the distribution of these words (the size of the word in the cloud indicates its frequency in the dataset).

The papers titles, abstracts and keywords contain 195 occurrences of the word “IoT” or “Internet of Things”, which put it in the first place before the others. Table 4 shows the frequencies of the most popular words (over 40 occurrences). When looking to less popular words, we can find “design” (28 occurrences) and “modeling” (19 occurrences). “Pervasive” is only present 24 times in the dataset, which means that this specific term is not so used in the literature.

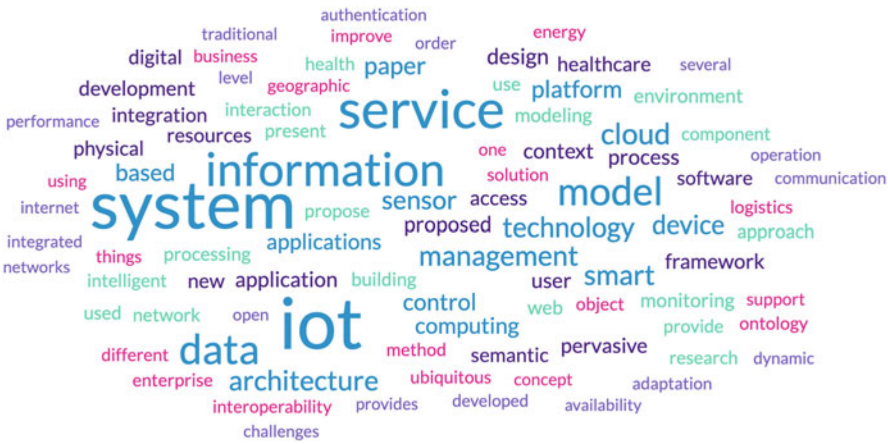


Fig. 4 Word cloud

Table 4 Popular words frequency in the titles, abstracts and keywords

Word	Frequency	Word	Frequency	Word	Frequency
IoT	195	Model	86	Technology	46
System	179	Cloud	53	Sensor	42
Service	135	Management	49	Device	41
Information	111	Smart	49		
Data	94	Architecture	48		

3.2 RQ2. How Is Addressed the Design and Modeling of Pervasive Information Systems in Research Proposals?

In this section, we looked about the type, nature, added value, usage and application domain of the strategies applied in the design-dedicated research proposals.

3.2.1 Paper Type

We categorized these papers according to the type of research approaches introduced by Wieringa et al. (2006). The research approach applied in all the selected papers is "solution proposal". The authors propose a solution proposal improving the design of pervasive information system or handling a specific aspect of the pervasive systems such as security, access control at the design level. Most of the papers illustrate their proposition on an example but they cannot be qualified as experience papers.

Table 5 Nature of the proposal

Nature	Number	Percentage	References
Framework	21	46.66%	Zschörnig et al. (2018), Zimmermann et al. (2018), Shang et al. (2016), Tai et al. (2019), Qu and Hou (2017), Wang et al. (2018), Thangaraj et al. (2016), Nespoli et al. (2019), Mongiello et al. (2016), Mingozzi et al. (2016), Lyu et al. (2021), Li et al. (2017), Korzun (2016), Howell et al. (2017), Gkioulos et al. (2019), Triantafyllidis et al. (2016), Kashmar et al. (2021), Donnal (2020), Dave et al. (2018), AlSuwaidan (2019), Santiago et al. (2019)
Framework on specific domain	11	24.44%	Xu et al. (2017), Songsom et al. (2020), Razzaq et al. (2020), Li (2016), Gill et al. (2017), Bottaccioli et al. (2017), Tahmasbi et al. (2016), Herrera-Quintero et al. (2016), Chen and Lin (2019), Celesti et al. (2019), Guo et al. (2020)
Model modification	5	11.11%	Zimmermann et al. (2017), Schirmer et al. (2016), Kirchhof et al. (2020), Kayes et al. (2018), Aimene and Rassoul (2017)
New model	8	17.77%	Zúñiga-Prieto et al. (2018), Zhang et al. (2016), Nebhani et al. (2017), Liu et al. (2018), Jin et al. (2017), Feng et al. (2017), Fatma et al. (2016), Hussain and Wu (2018)

3.2.2 Nature of the Proposal

The proposal given in the selected papers can be of a different nature.

- **Framework.** The paper offers a new architecture or framework to design systems using IoT.
- **Framework on Specific Domain.** The paper proposes a new architecture or framework using IoT on a specific domain.
- **Model modification.** The paper uses an existing model and offers some improvement to take into account IoT data.
- **New model.** The proposal offers a new model to take into account IoT data in systems.

Table 5 shows the distribution of the selected papers following the nature of their proposal.

Most of the selected papers (32) are proposing a framework or an architecture, either generic or for a specific domain.

Proposition of a **"New model"** at the design phase is the output of eight papers. It could be used to enhance an aspect of a PIS (for example – access control), to describe the interaction between service layer and physical layer or to integrate the semantic dimension to improve the data reasoning embedded in the PIS.

"Model modification" is associated to only five papers. It can be concerned by a modification of a product model such as state transition diagram, a standard description language to orchestrate services or a model process of an existing design methodology.

3.2.3 Added Value of the Proposal

Each proposal has a specific added value. We identify four possible types of value the proposals can offer. Table 6 indicates the repartition of the papers following the added value specificities.

- **Product model.** The proposal offers a specific product model to describe the concepts of the system.
- **Way of Working.** The source describes a set of steps to design the system.
- **Specific localization of the IoT use – domain specific.** The selected papers promote an architectural framework specific to a domain. The added value of these papers is to envision where the IoT services can be located in a specific application domain.
- **Quality aspect enhancement of the IoT based system.** The authors focus on a specific aspect of the system to develop and discuss it at the design step.

Sometimes, papers have a combination of added values, as they propose way of working and models. It happens when the papers promote an architectural framework based on several layers and provide specific concepts for each of them. In this case, they use layers to organize the design process in steps and for each step they propose a specific concept to model or design the system.

A main part of the works proposes some design or modeling part, either as a product model (7 papers), a way of working (12 papers) or both (14 papers). Seven sources are helping to see where the IoT services can be localized for a specific domain, like the system ports or the digital footprint for instance. Seven papers propose an enhancement of a quality aspect of the IoT system, like the confidentiality, the user authentication and profiling or even access control services.

3.2.4 Usage of the IoT Based System

Pervasive information systems are usually seen, in the literature, as IoT Systems. We studied the different sources to identify the purpose of the IoT systems to design.

- **Data-oriented system.** This type means that the pervasive systems are only viewed to capture, manage and organize the pervasive information. It means that IoT devices are only considered as sensors.
- **Monitor & control systems.** This type is used when the pervasive systems are used to implement a smart monitor and control systems such as in smart cities, smart home, smart health care system, etc.
- **Business improvement**. This type is used when the IoT systems are used as a way to improve the business processes of the organization by adding IoT devices in a physical environment to capture data as well as to change the enactment of business processes.
- **Adaptation of service.** This type focuses only to adapt or recommend services according to the user's context.

Table 6 Added value of the proposal

Added value	Number	Percentage	References
Product model	21	46.66%	Zúñiga-Prieto et al. (2018), Zschörnig et al. (2018), Zhang et al. (2016), Shang et al. (2016), Nebhani et al. (2017), Zimmermann et al. (2017), Schirmer et al. (2016), Liu et al. (2018), Li et al. (2017), Korzun (2016), Jin et al. (2017), Triantafyllidis et al. (2016), Tahmasbi et al. (2016), Kirchhof et al. (2020), Herrera-Quintero et al. (2016), Feng et al. (2017), Fatma et al. (2016), Dave et al. (2018), Celesti et al. (2019), Hussain and Wu (2018), Kayes et al. (2018)
Way of working	26	57.77%	Zúñiga-Prieto et al. (2018), Zschörnig et al. (2018), Zimmermann et al. (2018), Zhang et al. (2016), Shang et al. (2016), Xu et al. (2017), Wang et al. (2018), Thangaraj et al. (2016), Liu et al. (2018), Li et al. (2017), Korzun (2016), Howell et al. (2017), Gill et al. (2017), Bottaccioli et al. (2017), Triantafyllidis et al. (2016), Tahmasbi et al. (2016), Kirchhof et al. (2020), Herrera-Quintero et al. (2016), Donnal (2020), Dave et al. (2018), Celesti et al. (2019), AlSuwaidan (2019), Guo et al. (2020), Hussain and Wu (2018), Santiago et al. (2019), Aimene and Rassoul (2017)
Specific localization of the IoT use – domain specific	5	11.11%	Qu and Hou (2017), Songsom et al. (2020), Razzaq et al. (2020), Li (2016), Chen and Lin (2019)
Quality aspect enhancement of the IoT based system	7	15.55%	Tai et al. (2019), Nespoli et al. (2019), Mongiello et al. (2016), Mingozzi et al. (2016), Lyu et al. (2021), Gkioulos et al. (2019), Kashmar et al. (2021)

- **Technical improvement.** Some articles are not dealing with the designing of the whole pervasive systems but only focusing on improving a technical aspect of such systems.

  Table 7 shows the distribution of the usages over the selected papers.

"Data-oriented system" usage:

- The main part of the selected papers focusses on how to design systems dealing with "pervasive information" in a generic manner (Zimmermann et al. 2018; Zhang et al. 2016; Shang et al. 2016; Schirmer et al. 2016; Korzun 2016; Donnal 2020; AlSuwaidan 2019; Santiago et al. 2019) or in a more specific domain (Xu et al. 2017; Tai et al. 2019; Qu and Hou 2017; Songsom et al. 2020; Razzaq et al. 2020; Thangaraj et al. 2016; Li et al. 2017; Howell et al. 2017; Gill et al.

Table 7 Usage of the IoT system

Nature	Number	Percentage	References
Data-oriented system	26	57.77%	Zimmermann et al. (2018), Zhang et al. (2016), Shang et al. (2016), Xu et al. (2017), Tai et al. (2019), Qu and Hou (2017), Songsom et al. (2020), Razzaq et al. (2020), Thangaraj et al. (2016), Schirmer et al. (2016), Li et al. (2017), Korzun (2016), Howell et al. (2017), Gill et al. (2017), Bottaccioli et al. (2017), Triantafyllidis et al. (2016), Herrera-Quintero et al. (2016), Donnal (2020), Dave et al. (2018), Chen and Lin (2019), Celesti et al. (2019), AlSuwaidan (2019), Guo et al. (2020), Hussain and Wu (2018), Santiago et al. (2019), Kayes et al. (2018)
Technical improvement	11	24.4%	Zúñiga-Prieto et al. (2018), Zimmermann et al. (2017), Nespoli et al. (2019), Mongiello et al. (2016), Mingozzi et al. (2016), Lyu et al. (2021), Liu et al. (2018), Jin et al. (2017), Gkioulos et al. (2019), Kashmar et al. (2021), Fatma et al. (2016)
Monitor and control system	3	6.67%	Wang et al. (2018), Kirchhof et al. (2020), Feng et al. (2017)
Business improvement	4	8.88%	Zschörnig et al. (2018), Li (2016), Tahmasbi et al. (2016), Aimene and Rassoul (2017)
Adaptation of services	1	2.22%	Nebhani et al. (2017)

2017; Bottaccioli et al. 2017; Triantafyllidis et al. 2016; Herrera-Quintero et al. 2016; Dave et al. 2018; Chen and Lin 2019; Celesti et al. 2019; Guo et al. 2020; Hussain and Wu 2018; Kayes et al. 2018).

- Four papers (Qu and Hou 2017; Songsom et al. 2020; Razzaq et al. 2020; Chen and Lin 2019) propose a framework to deal with IoT sensors-based systems without other added value than helping to understand where to locate the pervasive information in that domain (Framework on Specific Domain – Specific, localization of the IoT use – domain specific).
- Six papers provide an architectural framework for IoT sensors-based systems specific to an application domain with a way of working (Gill et al. 2017; Bottaccioli et al. 2017; Guo et al. 2020) and with models (Xu et al. 2017; Celesti et al. 2019; Herrera-Quintero et al. 2016).
- Eleven papers provide an architectural framework for IoT sensors-based systems with a way of working (Xu et al. 2017; Howell et al. 2017; Donnal 2020; AlSuwaidan 2019; Santiago et al. 2019) and with models (Shang et al. 2016; Thangaraj et al. 2016; Li et al. 2017; Korzun 2016; Triantafyllidis et al. 2016; Dave et al. 2018).
- Two papers (Zhang et al. 2016; Hussain and Wu 2018) propose a new model and a way of working for IoT sensors based systems. (Zhang et al. 2016)

proposes a modeling technique for the interactions between the sensor and the geographic environment in emerging sensor, whereas (Hussain and Wu 2018) defines semantic annotations in a model to maintain the comprehension between the application layer and the physical layer.

The three remaining papers are:

- Tai et al. (2019) propose an authentication framework to ensure reliable and anonymous data-oriented services with anonymity, availability and security (*architectural framework – quality aspect enhancement of the IoT based system*).
- Kayes et al. (2018) modifies a traditional state-transition-diagrams to specify the dynamic state change of a context (*Model modification, Product Model*)
- Schirmer et al. (2016) proposes to extend enterprise architectures for the "smart Port" application domain (*model modification, Product model*).

In the "**monitor & control systems**" usage, the aim of the pervasive information system is to monitor and control activities performed in a physical environment. It is handled by only three papers and it concerns smart building (Wang et al. 2018), smart home (Kirchhof et al. 2020) and smart industry (Feng et al. 2017). In more details:

- Wang et al. (2018) proposes an architectural framework to build an operation management of cloud ecosystem IoT platform for smart home device level, networking level, IoT platform level and operation management applications level (*way of working & models*).
- Kirchhof et al. (2020) promotes at the design stage a model-driven digital twin construction for synthesizing the integration of cyber-physical systems with their information systems. Authors propose a *modified existing model* to handle specifically a "Smart home" system.
- Feng et al. (2017) targets a context-aware supervision for logistics asset management in the smart industry field. The authors propose concepts (*new model*) at the design level to the system implementation.

The **"Business improvement"** usage is the category we are interested in because it considered the information systems can be improved or extended by "pervasive services" which are related to IoT sensors and IoT actuators. This category is covered by only four papers where three are specific to a domain (smart energy (Zschörnig et al. 2018), smart logistics (Li 2016) and Smart patient care (Tahmasbi et al. 2016)) and only one is generic (Aimene and Rassoul 2017). In more details,

- Li (2016) promotes an architectural framework at the design level to improve the supply-chain business systems by using a RFID technology to track the circulation of the product. The added value of this proposition is to help the user to understand where the pervasive services are located and the impact at the business level (*Localized the use of IoT – domain specific*).
- Zschörnig et al. (2018) provides an architectural framework including concepts specifics to pervasive IS and models at three levels: *integration layer, data & analytics layer and IoT aware process layer*. It is used to propose a way of

working at the design phase as well as models to use to specify each layer (*Way of Working & model*).

- Tahmasbi et al. (2016) promotes an architectural framework for a pervasive healthcare system focused on availability, interoperability, and performance, wherein components, their relationships and the necessary constraints are defined to contribute to easier implementation of these systems. At the design phase, it proposes *a way of working and models* to specify the pervasive healthcare system.
- Aimene and Rassoul (2017) proposes to extend Booch's design methodology[1] to handle ubiquitous specification in a generic manner. The specificity of the PIS is proposed by adding to the traditional way of working two early steps to deal with ubiquitous requirements specification and context specification (*Way of working*).

The **"Adaptation of service"** usage is covered by only 1 paper (Nebhani et al. 2017) proposing a formal Context-awareness model at the design phase based on an ontology traceability to provide adaptive services to accomplish a specific goal at any moment and any place (*new model – Product model*). The IoT system is user-centric and focusing on mobile devices.

The **"technical improvement"** category concerns 11 papers where only one is specific to a domain (*smart water management* (Liu et al. 2018)). The aspects of the PIS targeted by these papers are the following.

- Three papers are dealing with *access control aspect* of the PIS at the design phase by providing specific framework (Zimmermann et al. 2017; Nespoli et al. 2019; Kashmar et al. 2021).
- Two papers add *semantic facility with ontologies to context* at the design phase (Mingozzi et al. 2016; Fatma et al. 2016),
- Three papers deal with the *interaction between IoT physical layer to the service layer* with specific models at the design phase (Zúñiga-Prieto et al. 2018; Zimmermann et al. 2017; Liu et al. 2018) but (Zimmermann et al. 2017) extends the TOSCA standard to automate orchestration of services.
- One paper (Lyu et al. 2021) proposes a *support control aspect* in PIS as a service with a framework at the design phase including a hierarchy of ontologies.
- One paper (Mongiello et al. 2016) targets the *reflexivity capability* required in PIS to integrate it in context-aware design of reflective middleware.

3.2.5 Application Domain

One of our goals is to analyze the impacted domains. Over our 45 papers, 19 papers are completely generic and don't address a particular domain. On the remaining 26 papers, 20 are concerned about a specific application domain, whereas the

[1] Booch's design method: Grady Booch published in 1992 and revised in 1994 an object-oriented design method called OMT. It was widely used in software engineering for object-oriented analysis and design.

Table 8 Application domains

Application domain	Number	Main domain	Case study
Smart applications for persons	**12**		
Smart healthcare	8	Smart healthcare monitoring (Xu et al. 2017) Smart patient healthcare (Triantafyllidis et al. 2016; Celesti et al. 2019; Tai et al. 2019; Thangaraj et al. 2016; Tahmasbi et al. 2016)	Hussain and Wu (2018), Kayes et al. (2018)
Smart home	4	Smart home building (Wang et al. 2018; Bottaccioli et al. 2017)	Mingozzi et al. (2016), Kirchhof et al. (2020)
Smart applications for environment	**2**		
Smart natural resource management	2	Smart water management (Liu et al. 2018; Howell et al. 2017)	
Smart applications for society	**4**		
Smart city	2	Smart urbanism (Chen and Lin 2019; Guo et al. 2020)	
Smart education	2	Smart campus (Dave et al. 2018) Smart university (Songsom et al. 2020)	
Smart applications for enterprises	**8**		
Smart agriculture	1	(Gill et al. 2017)	
Smart business management	2	(Li et al. 2017)	Lyu et al. (2021)
Smart industry	3	Smart energy (Zschörnig et al. 2018) Smart logistics (Li 2016)	Smart logistics (Feng et al. 2017)
Smart transportation	2	(Razzaq et al. 2020; Herrera-Quintero et al. 2016)	

other 6 gives some generic solution illustrated on a domain case study. For the 26 papers either specific or illustrating their generic solution on a specific domain, we refer to the smart applications taxonomy defined in (Kornyshova et al. 2022) to characterize the domain. The following table shows the number of each paper for each represented domain (Table 8).

We can conclude that the selected papers cover a large panel of smart applications domains. This means that any domain can be concerned and impacted by design and modeling in pervasive information systems.

3.2.6 Discussion

The analysis of the selected papers shows that only seven papers (Wang et al. 2018; Kirchhof et al. 2020; Feng et al. 2017; Zschörnig et al. 2018; Li 2016; Tahmasbi et al. 2016; Aimene and Rassoul 2017) deal with a PIS compliant with the definition detailed in chapter "What Is a "Pervasive Information System" (PIS)?". The "Business improvement" and "control & monitor system" are the usage types compliant with our PIS definition. More than half of the papers twenty-six aim at designing a system to manage "pervasive information" from IoT-sensors based systems and less than a quarter of the papers concern an improvement of a technical aspect of a PIS.

The PIS vision, developed in chapter "What Is a "Pervasive Information System" (PIS)?", is structured by a set of layers from the infrastructure layer to the application or business process layer. In addition, it includes two main flows across layers – the bottom-up one corresponding to the data flow whereas the top-down one represents the adaptation flow. The bottom-up data flow represents the way of managing "pervasive information" from the lower layer to the upper layer. This flow is tackled by most of the research works. However, the top-down flow for adaption purpose is not handled explicitly in the selected papers on IoT or pervasive systems.

The seven papers compliant to our PIS definition deal with (1) an architectural framework connecting the lower layers (infrastructure or physical) to the upper layers (application or business processes) and (2) deal with the bottom-up data flow across layers. However, they are not mentioned explicitly the top-down adaptation flow. The architecture layers are used by four papers (Zschörnig et al. 2018; Wang et al. 2018; Tahmasbi et al. 2016; Feng et al. 2017) to structure the way of working at the design phase and only one (Aimene and Rassoul 2017) extends a traditional Information system design method (Booch's design methodology). (Kirchhof et al. 2020) adapts the "digital twin" approach to integrate the cyber-physical systems with their information systems. Five papers (Zschörnig et al. 2018; Wang et al. 2018; Tahmasbi et al. 2016; Kirchhof et al. 2020; Feng et al. 2017) propose at the design phase at least one modelling technique adapted to the PIS.

Beside these seven papers, we would like to underline the fact that (Schirmer et al. 2016) extends existing enterprise architectures approaches for building IoT-based systems.

Before concluding on RQ2, we can highlight some research works that are based on new trends for sharing on the cloud "pervasive information" such as:

- Razzaq et al. (2020) is related to the Cloud of Thing (CoT). Cloud computing, coupled with IoT, gathers data from remote areas with wireless sensors and organizes them in an added-value service facility for a specific domain.
- Korzun (2016) uses the "smart space approach". Smart spaces define a software development approach that enables creating service-oriented information systems for emerging computing environments of the Internet of Things (IoT). Such environments follow the paradigms of ubiquitous and pervasive computing

and provide a growing multitude of digital networked devices surrounding their human users.
- AlSuwaidan (2019) handles the data management on Internet of Everything (IoE). The IoE is defined on top of the IoT by adding the human element to the IoT network. In particular, the IoE can improve quality of lives via smart connection between people, processes, data, and things. The ITU Telecommunication Standardization Sector characterizes the IoE as "*a worldwide base for the data society, empowering propelled administrations by interconnecting (physical and virtual) things taking into account existing and advancing interoperable data and correspondence innovations*" (Majeed 2017).

In addition, two papers address a relevant point for designing and developing a PIS:

- Dave et al. (2018) emphasizes the fact that pervasive information systems dealing with real space like a building or a University, an Airport, a station, etc. needs to integrate a "Building Information Modelling" (BIM) to at least the physical infrastructure IoT layer to be able to reason on it at the application layer.
- The top-down adaptation flow mentioned in our PIS vision can be handled with a reflexivity capability we can at least develop at the physical layer by a context-aware design of reflective middleware (Mongiello et al. 2016).

As it is stated in (Schirmer et al. 2016), "Today, many companies use models and tools that are based on enterprise architecture approaches for improving the alignment between business and IT. For managing the enterprise architecture, appropriate models need to be built, kept up-to-date and should be taken as a basis for decision making regarding issues that affect the relation between business and IT." That's why existing enterprise architecture (EA) models have to be extended or rethink to handle our PIS vison.

The research works exposed by the selected papers proposes an architectural framework, ways of working or/and models for a specific domain, a specific aspect of a PIS in order to connect the physical layer to the application layer. Only one paper (Aimene and Rassoul 2017) refers to a traditional Information system design methodology or modelling techniques (Booch's design methodology). However, the extension which could be in (Aimene and Rassoul 2017) but also external sources such as in (Zimmermann et al. 2015) and (Bassi et al. 2013) do not help stakeholders to envision the use of the IoT to improve business processes, it is why a domain-dependent approach could be more efficient to guide stakeholders to build PIS.

3.3 RQ3. How Are Met the PIS Requirements in These Design-Dedicated Research Proposals?

One of our main goals is to analyze the fulfilling of the PIS requirements defined in chapter "What Is a "Pervasive Information System" (PIS)?". Table 9 shows the fulfilled PIS requirements (with an X in the cell) for each selected paper. Sometimes,

Table 9 Requirements

Article	Context awareness	Heterogeneity	Transparency	Requirements satisfaction	Adaptation
Zúñiga-Prieto et al. (2018)	n/a	X	X	X	n/a
Zschörnig et al. (2018)	X	X	X	X	X
Zimmermann et al. (2018)		X	X	n/a	n/a
Zhang et al. (2016)	n/a	X	X	X	n/a
Shang et al. (2016)	n/a	X	X	X	n/a
Xu et al. (2017)		X	n/a	n/a	n/a
Tai et al. (2019)		X	n/a	X	n/a
Qu &and Hou (2017)		X	X	X	n/a
Songsom et al. (2020)	n/a	X	n/a	X	n/a
Razzaq et al. (2020)	X	X	X	X	X
Nebhani et al. (2017)	X		X	X	X
Zimmermann et al. (2017)	n/a	X	n/a	X	n/a
Wang et al. (2018)	X	X	X	X	X
Thangaraj et al. (2016)	n/a	X	X	X	n/a
Schirmer et al. (2016)		X	X	X	n/a
Nespoli et al. (2019)	X	X	n/a	n/a	n/a
Mongiello et al. (2016)	X	X	n/a	X	X
Mingozzi et al. (2016)	X	X	n/a	n/a	X
Lyu et al. (2021)	X	X	n/a	X	n/a
Liu et al. (2018)	n/a	X	n/a	X	n/a
Li (2016)			n/a	X	n/a
Li et al. (2017)	n/a	X	X	X	n/a
Korzun (2016)	n/a	X	X	X	n/a
Jin et al. (2017)	n/a	X		X	X
Howell et al. (2017)	X	n/a	n/a	X	n/a
Gkioulos et al. (2019)	n/a	X	n/a	X	n/a
Gill et al. (2017)	n/a	X	n/a	X	n/a
Bottaccioli et al. (2017)	X	X	n/a	X	n/a
Triantafyllidis et al. (2016)	X	X		X	n/a
Tahmasbi et al. (2016)	X	X	X	X	n/a
Kirchhof et al. (2020)	X	X	n/a	X	
Kashmar et al. (2021)	X	X	n/a	n/a	n/a
Herrera-Quintero et al. (2016)	n/a	X	n/a	n/a	n/a
Feng et al. (2017)	X	X	n/a	X	
Fatma et al. (2016)	X	n/a	X	X	X
Donnal (2020)	X	X	n/a	X	n/a
Dave et al. (2018)	X	X	n/a	X	n/a
Chen and Lin (2019)	X	X	n/a	X	n/a
Celesti et al. (2019)	X	X	n/a	X	n/a
AlSuwaidan (2019)	X	X	n/a	X	n/a
Guo et al. (2020)	X	X	n/a	X	n/a
Hussain and Wu (2018)	X	X	n/a	X	n/a
Santiago et al. (2019)	X	X	n/a	X	n/a
Kayes et al. (2018)	X	X	n/a	n/a	n/a
Aimene and Rassoul (2017)	X	n/a	n/a	X	n/a

the proposal does not give enough information to be able to decide and, in this case, a non-applicable sign (n/a) was put in the corresponding cell. Empty cells mean that the PIS requirement is not fulfilled.

- **Heterogeneity.** This requirement is present in 88.9% of the sources (fourty papers) as it is quite usual to manage several kind of IoT devices at the physical layer for a PIS. Two papers do not satisfy this requirement (empty cell) because at the physical level they choose to integrate only one technology ((Nebhani et al. 2017) with mobile phone technology and (Li 2016) with RFID technology). Three papers are not concerned ("n/a" cell) by the requirement because their proposal does not manage or are not concerned by the physical layer (Howell et al. 2017; Fatma et al. 2016; Aimene and Rassoul 2017).

- **Requirements satisfaction**. 88.44% of the sources are concerned about meeting the user needs or the purpose of the IoT based systems to improve the overall performance of the organization (thirty-eight papers). They meet this requirement when the proposal includes the application or business process layers in the architectural framework. Six papers are not concerned by this requirement ("n/a" cell) because they are only tackling in their proposal the data access control (Nespoli et al. 2019; Kashmar et al. 2021; Kayes et al. 2018) or are dedicated only to share or gather data (Xu et al. 2017; Zimmermann et al. 2018; Herrera-Quintero et al. 2016) without referring to the PIS at the designing phase.
- **Context awareness.** It is considered in 57.8% of the sources (twenty-six papers). This requirement is satisfied by the research works where data are captured in the environment and also identified by the authors as a context information of entities and not only raw data. Twelve papers are not concerned by this requirement ("n/a" cell) because they are related to build a data-oriented IoT systems (IoT sensors-based systems) but they are concerned about capturing, sharing and distributing data without using them (Zhang et al. 2016; Shang et al. 2016; Songsom et al. 2020; Li et al. 2017; Gill et al. 2017; Herrera-Quintero et al. 2016) or because their proposal is to improve a technical aspect which is not related to context information and management (Zúñiga-Prieto et al. 2018; Zimmermann et al. 2017; Thangaraj et al. 2016; Liu et al. 2018; Jin et al. 2017; Gkioulos et al. 2019). Seven papers do not meet this requirement because they are related to the building of a data-oriented systems (Zimmermann et al. 2018; Xu et al. 2017; Tai et al. 2019; Qu and Hou 2017; Schirmer et al. 2016; Li 2016; Korzun 2016), which observe and use data without considering these as context information of entities.
- **Transparency.** This requirement is not a relevant characteristic for this bunch of sources as only fifteen papers are concerned about it. The purpose of this requirement is mainly to hide the heterogeneity of the IoT devices at the physical layer (Zúñiga-Prieto et al. 2018; Zschörnig et al. 2018; Zimmermann et al. 2018; Zhang et al. 2016; Shang et al. 2016; Qu and Hou 2017; Razzaq et al. 2020; Wang et al. 2018; Thangaraj et al. 2016; Schirmer et al. 2016; Li et al. 2017; Korzun 2016; Tahmasbi et al. 2016) or to hide the complexity of the adaptation process (Nebhani et al. 2017; Fatma et al. 2016). The proposal of the two papers (Jin et al. 2017) and (Triantafyllidis et al. 2016) do not meet this requirement as the former paper proposes a model helping to choose the selected service without hiddening the heterogeneity and the adaptation process whereas in the latter the heterogeneity is not handled at all. Twenty eight papers are not concerned by this requirement (n/a cells) either because their proposal aim at designing data-oriented system or monitor & control system and they do not hide the

heterogeneity or because their proposal is a technical improvement which is not concerned by heterogeneity or which do not hide at all the heterogeneity.
- **Adaptation**. Not a lot of sources are taking this particular requirement into account. Only 15.56% of the proposals (Mingozzi et al. 2016; Jin et al. 2017; Fatma et al. 2016; Mongiello et al. 2016; Wang et al. 2018; Zimmermann et al. 2017; Nebhani et al. 2017) meet this requirement as they handle the selection and/or the adaptation of services according to quality criteria or context information. Two papers (Kirchhof et al. 2020; Feng et al. 2017) do not satisfied this requirement because the monitor & control systems they target does not include the selection or adaptation of services. Thirty six papers are not concerned by this requirement because they are targeting a data-oriented system or technical improvement without relation with adaptation.

Only two papers fulfill all the PIS requirements as defined in the first chapter.

- Zschörnig et al. (2018) proposes an architectural concept, divided into three technical layers (integration, data and analytics, and IoT-aware processes) and a software prototype called SEPL. This proposal also fulfill two of the additional characteristics: it support the user's business needs in a predictable and controlled manner (Determinism) and collect and process heterogeneous data automatically (Automatic).
- In Wang et al. (2018), the authors propose a building operation management cloud ecosystem for smart buildings, containing several levels, namely the building operation management application level, the IoT platform, networking level and the device level. However, it is difficult to determine if the proposal fulfills some additional characteristics.

Three papers fulfill 4/5 of the PIS requirements.

- Razzaq et al. (2020) introduced an edge information system for intelligent Internet of Vehicle, including edge caching, edge computing, and edge AI. Authors present platforms, design methodologies, and key use cases. It satisfies Context awareness, Heterogeneity, Transparency and Requirements satisfaction. It is difficult to determine if this proposal fulfill additional characteristics. However, if only one of them has to be fulfilled, it can only be the "Automatic" one.
- Tahmasbi et al. (2016) propose a software architecture for a cloud-based healthcare system for mobile patients. It is focused on non-functional requirements including availability, interoperability, and performance. The cloud major component is designed in the form of multiple independent clouds and also makes use of virtualization concept. The proposal satisfies Context awareness, Heterogeneity, Transparency and Requirements satisfaction. It is difficult to determine if the proposal fulfills some additional characteristics.
- Fatma et al. (2016) adds contextual information to the semantic web service description to ensure the pervasive system adaptation and to change the web service behavior depending on the contextual information categories. Authors propose a methodological approach to assist the designers to develop PIS

instances based on semantic web services and to adapt these instances to the user's need in a specific contextual situation. This work satisfies Context awareness, Transparency, Requirements satisfaction and Adaptation. However it is difficult to determine if it fulfills some additional characteristics.

Twenty-four sources fulfill 3/5 of the PIS requirements, each of them satisfying at least Heterogeneity and Requirement satisfaction. On this subset, 62% satisfy Context awareness, 33% Transparency and 8% Adaptation.

4 Conclusion and Open Issues

We conducted a systematic mapping study on papers addressing design and modeling in pervasive information systems. We had three research questions.

- To answer to *RQ1* (What is the distribution evolution of the sources?), we studied the distribution of the selected papers over time and issues and identified the most frequent words present in the selected sources.
- To answer *RQ2* (How is addressed the design and modeling of pervasive information systems in research proposals?), we then characterized the selected papers following the type, nature of the proposal, usage of the IoT system and application domain. It gave us some insight about the proposals in each of the sources.
- To answer to *RQ3* (How are met the PIS requirements presented in the first chapter of the book in these design-dedicated research proposals?) we finally looked if the proposal were fulfilling the requirements identified for pervasive information systems. Only two papers were fulfilling 100% of the PIS requirements and three papers 4/5 of them.

This literature review leads us to draw some conclusions. There are works in the literature which propose some interesting value about design and modeling in PIS but a common terminology is required in the field to be able to compare and link all the existing proposals on a more efficient way.

Our PIS vision uses a two-way flow between the layers: the data flow from the infrastructure layer to the management layer – bottom-up flow – and the adaptation flow the other way around – top-down flow (see chapter "What Is a "Pervasive Information System" (PIS)?"). The bottom-up flow is mostly taken into account in the selected works of our dataset, whereas the top-down one is usually ignored. The reflexivity capability and the context-awareness in middleware are important elements but are not usual in information system development method. New methodologies must be defined to handle correctly adaptative systems. We also highlighted that a domain-dependent approach could be more efficient to guide stakeholders to build PIS and to help them to envision the use of the IoT to improve business processes. Moreover, existing enterprise architecture (EA) models have to be extended or redesigned to handle our PIS vison and to take into account the two-way flows of the PIS dynamics. Information about building (BIM) and physical environment should be integrated in the design methodology for domain-specific PIS like smart university, smart airport, and so on.

The majority of the systems used in the selected works can't be qualified as pervasive information system as we have defined it earlier as they mostly have a pervasive information vision (they use only the bottom-up flow). They do not fulfill all of the five requirements stated in chapter one and usually don't give any information about the additional characteristics.

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