Providing a Consensus Definition for the Term "Smart Product"

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Abstract—**The term "Smart Product" has become commonly used in recent years. This is because there has been an increasing interest in these kinds of products as part of the consumer goods industry, impacting everyday life and industry. Nevertheless, the term "Smart Product" is used with different meanings in different contexts and application domains. The use of the term "Smart Product" with different meanings and underlying semantics can create important misunderstandings and dissent. The aim of this paper is to analyze the different definitions of Smart Product available in the literature, and to explore and analyze their commonalities and differences, in order to provide a consensus definition that satisfies, and can therefore be used by, all parties. To embrace the identified definitions, the concept of "Smart Thing" is introduced. The methodology used was a systematic literature review. The definition is expressed as an ontology.**

Keywords—smart product; intelligent product; smart thing; software engineering innovation; innovation; systematic literature review; SLR; thematic synthesis

I. INTRODUCTION

Historically, the main goal of the development of software intensive systems has always been product delivery within time and cost, and ensuring product quality. Currently, it is necessary to innovate in software product development to outperform in the highly competitive marketplace. Over the last decade, companies have focused their efforts on presenting innovative products that make them stand out from other companies.

The use of new technologies has boosted product innovation. The so-called Smart Products have emerged as products that are able to use information about themselves and about the environment in which they run, and that are able to inter-operate with other products. This turns out product functionalities that outmatch those offered by the competitors' products.

Skyrme [1] introduces the potential value of Smart Products as elements that are based on the use of information or knowledge, that are present, and that provide better functionality or service that can significantly increase the value of relationship-based services. And Dedecker [2] highlights that Smart Product development is a path to innovation.

Smart Products, as a class of product that is available in the market, have grown significantly over the past decade. When we searched for "Smart Products" in the Google search system[1] we obtained over 600,000 results[2], while for other logically related concepts, for example "Intelligent Products," we obtained over 115,000. This may provide us with a glimpse of the relevance of the so-called Smart Products in our society. Smart Products may include significantly different applications, such as systems for a mobile recommendation agent [30], a cooking guide [38], a context aware in-vehicle driver information application [38], an intelligent washing machine [37], common consumer goods [28,35], or a production control system [3].

However, while some definitions for Smart Products exist, it is not possible to find an agreed upon, generally accepted, and well recognized definition of Smart Products in the literature. Back in 1996, Dhebar [4] presented a detailed analysis of the impact of IT in products to make them "Smart." While Dhebar claims that models for classifying products by characteristics would be very useful, he does not provide a specific model. Rijsdijk [5] introduces that "smart products are able to collect, process and produce information, and can be described to 'think' for themselves"; Zaeh et al. refer to Smart Products without providing a definition in [3]: "This paper introduces a concept for a cognitive production planning and control system, in which so-called smart products store knowledge about the production process and its current state." The picture becomes even more confusing because some other terms and concepts overlap Smart Product, such as "Intelligent Products," "Intelligent Object," and "Smart Objects." As a matter of fact, some authors, e.g., Kiritsis et al. in [6], consider that Intelligent Product is a concept equivalent to Smart Product. Kiritsis et al. in [6] state that "The so called 'Intelligent Products' and 'Smart Products'–these two terms can be used interchangeably."

Meyer et al. [7] provide a detailed survey on Intelligent Products, and claim that a comprehensive classification of Intelligent Products that covers all of the aspects of the field is required. According to Meyer et al. [7], this classification might be used for analyzing different information architectures according to what kind of Intelligent Products and what parts

[1] http://www.google.com

[2] Search performed on January 10^{th}, 2013.

of the product lifecycle they are suited for. According to Mühlhäuser [8], a concise definition of Smart Products should be established and widely agreed upon if a corresponding new research field and community shall emerge.

Several problems arise from this lack of definition. First, without a common base, it is very difficult to build a design theory specifically for these kinds of systems. Second, it is not possible to produce a quality model, and to assess product quality; third, any discussion may end in a lack of mutual understanding. Therefore, establishing a definition of Smart Product becomes a priority. To reach an agreed upon definition of the Smart Product concept is essential to establish a starting point through which researchers can determine which characteristics should exist for a product to be considered a Smart Product. Otherwise, the danger that Smart Product ends up as just another buzzword is a real threat.

Our contribution is a step ahead of Meyer et al. [7] and Mühlhäuser's [8] work. It presents the conclusions of a research project of which the objective was to analyze existing academic papers dealing with Smart Products to identify if a common understanding for the definition of Smart Product could be reached. As is explained in the next sections, one of the early conclusions was that it was necessary to consider related terms, such as Intelligent Systems, to reach a consensus definition, that is, an understanding that is common and acceptable to all parties.

The rest of the paper is structured as follows: Section II presents the research method, which was a systematic literature review (SLR) and thematic synthesis. Section III describes the main findings from the SLR. Section IV introduces the result of the thematic synthesis such that the definition of Smart Product is described as models that can be regarded as ontologies. Finally, Section V presents some conclusions and future work.

II. RESEARCH METHOD

A. *Selecting*

This study was performed as a systematic literature review based on the original guidelines proposed by Kitchenham [9]. This method has been used successfully in software engineering [10][11][12][13], and the main disadvantage is that it requires considerably more effort than a traditional review.

B. *Research Question*

The research question addressed by this study is:

RQ1. What is a Smart Product and which terms can define a Smart Product such that the result is a consensus definition?

C. *Search Strategy*

In order to answer our research question with a systematic literature review, we worked with a number of prestigious digital databases that are accessible from the tool MetaLib®, which is available at the Technical University of Madrid (UPM). The selected data sources are shown in Table I.

TABLE I. DATA SOURCES

Data Source
Compendex[a]
IEEE Explorer
Web of Science
Computer Database
Inspec[a]
CiteSeerX
Elsevier

[a] The ACM Digital Library publications were obtained through the Compendex and Inspec databases.

The search terms for the study were defined based on the research question, and to get the maximum number of possible outcomes in each electronic database. From the early stages of the study, it became obvious that it was necessary to consider not only "smart product" but also "intelligent product," "smart system," "intelligent system," "smart object" and "intelligent object." Actually, the references [4,5,6,27,37] deal with several of these concepts. All of these terms were used in a somewhat interchangeable way. Therefore, the following search string was established:

("smart" OR "intelligent") AND ("product" OR "system" OR "object")

D. *Inclusion and Exclusion Criteria*

Articles on the following topics were included:

- Scientific material written in English, and subjected to the normal scientific peer review process.
- Scientific material published between January 2008 and April 2012 was considered. In fact, as explained below, before January 2008 and after April 2012 no articles that matched the search string could be found.
- Scientific material on the central theme of software and systems engineering.

Articles on the following topics were excluded:

- Informal literature that was clearly not in accord with scientific methodology.
- Reports with poor arguments based on general opinions.
- Duplicate reports of the same study.

The analyzed documents were categorized using the reference management software Mendeley [14].

E. *Quality Assessment*

Each study was evaluated on the basis of rigor, credibility, and relevance. The criteria were based on six quality assessment (QA) questions. We summarize the quality assessment form in Table II.

F. *Data Extraction*

The data extraction process consisted of identifying the data required to answer the research questions. The data was formatted to show:

- The number of papers published per year.

- The research method used in each investigation, according to Cheng et al.'s classification [15].
- The kind of application software and system software used in each paper, according to Xu and Brinkkemper's classification [16].
- The Smart Product definition within each paper.
- The context in which the Smart Product definition is applied.

TABLE II. QUALITY CRITERIA

QA	Answer
Is the report based on research methods?	Yes/No
Is there a clear statement of the aims and objectives of the research?	Yes/No
Is there a clear description of the context in which the research was carried out?	Yes/No
Are there relevant studies included in the findings?	Yes/No
Are the results evaluated in accordance with objective criteria?	Yes/No
Is there a clear statement of findings?	Yes/No

G. Data Synthesis Strategies

We selected the narrative synthesis method to synthesize the extracted data. We selected this method given the heterogeneity of the studies we located, and because it has been used successfully in software engineering [17]. Keeping this in mind, we based our data synthesis on the process proposed by Popay et al. in [18] for performing data synthesis in systematic literature reviews.

III. FINDINGS

We identified 26 scientific papers on Smart Products, which were labeled from P1 to P26. Table III shows the selected papers.

TABLE III. CORRESPONDENCE BETWEEN EACH PAPER AND ITS REFERENCE

Id	Reference	Id	Reference
P1	[8]	P14	[19]
P2	[20]	P15	[21]
P3	[22]	P16	[23]
P4	[24]	P17	[25]
P5	[26]	P18	[3]
P6	[27]	P19	[28]
P7	[29]	P20	[30]
P8	[31]	P21	[32]
P9	[33]	P22	[34]
P10	[35]	P23	[6]
P11	[7]	P24	[36]
P12	[37]	P25	[38]
P13	[5]	P26	[39]

A. Overview of Studies

Regarding the year of publication, we found no scientific studies on Smart Products prior to 2008 that matched the search string. The number of publications remained constant during the searched period. This indicates the need to increase researchers' interest in this area to learn more about Smart Products. A significant aspect of this feature is that we found no scientific studies after 2012. This is important, because Smart Products as a topic cannot and must not be considered closed (Table IV).

TABLE IV. STUDIES BY PUBLICATION YEAR

Publication	Number	Percent
2008	6	23
2009	7	27
2010	5	19
2011	8	31

With respect to the research method used in each publication, we used the classification proposed by Cheng et al. in [15]. Table V gives an overview of the studies according to the research method. Most of the studies were conducted as a case study (69%). Furthermore, we could not find either pure industry reports or action research studies. Overall, these findings point to the need to design and use Smart Products in industrial environments.

TABLE V. STUDIES BY RESEARCH METHOD

Research method	Number	Percent
Case study	18	69
Industry report	0	0
Experiment	5	19
Survey	3	12
Action research	0	0
Not stated	0	0

Table VI shows the classification of the studies according to the kind of system software proposed by Xu and Brinkkemper [16]. We see that there is a trend toward addressing embedded software (62%).

TABLE VI. STUDIES BY SOFTWARE CLASSIFICATION

Software classification	Number	Percent
Micro program	3	12
Embedded software	16	62
Tailor-made software	9	35
Product software	6	23

B. What is a Smart Product, and which Terms Can Define a Smart Product so that the Result is a Consensus Definition?

To perform the extraction of this property, it was felt that, essentially, as in the other cases where this method has been applied, it should be an iterative process. The values obtained from repeated readings make up the basis of the definition of Smart Products.

In the literature, the most often used definitions of Smart Product were those offered by Maass and Janzen [40], Mühlhäuser [8], and the SmartProducts Consortium [20].

Maass and Janzen [40] identified three core requirements for Smart Products:

- (R1) adaptation to situational contexts.

- (R2) adaptation to actors that interact with products or product bundles.
- (R3) adaptation to underlying business constraints.

They refined these requirements through the following operational requirements:

1. Situatedness: recognition of situational and community contexts (R1).
2. Personalization: tailoring products according to buyer and consumer needs and affects (R2).
3. Adaptiveness: changing product behavior according to buyer and consumer responses and tasks (R2).
4. Pro-activity: anticipation of user's plans and intentions (R2).
5. Business awareness: consideration of business and legal constraints (R3).
6. Network capability: ability to communicate and bundle with other products (R3).

Mühlhäuser provided a definition of Smart Product in which, among other features, he highlights that a Smart Product can be either a physical object, such as software, or a service. According to Mühlhäuser [8]:

"A Smart Product is an entity (tangible object, software, or service) designed and made for self-organized embedding into different (smart) environments in the course of its lifecycle, providing improved simplicity and openness through improved p2u and p2p interaction by means of context-awareness, semantic self-description, proactive behavior, multimodal natural interfaces, AI planning, and machine learning."

The SmartProducts Consortium[3] refined the definition given by Mühlhäuser, providing the following definition [20]:

"A smart product is an autonomous object which is designed for self-organized embedding into different environments in the course of its life-cycle and which allows for a natural product-to-human interaction. Smart products are able to proactively approach the user by using sensing, input, and output capabilities of the environment thus being self-, situational-, and context-aware. The related knowledge and functionality can be shared by and distributed among multiple smart products and emerges over time."

M. Sabou et al. [20] compared the different features suggested by Maass and Janzen, Mühlhäuser, and the SmartProducts Consortium, and established that the common features that a product should have to be considered a Smart Product are: context-awareness, pro-activity, and self-organization.

Another term that was found often in the literature is "Intelligent Product." Smart Product and Intelligent Product are interchangeable concepts, according to McFarlane et al. [41], Kärkkäinen et al. [42], and Venta [43]. On the basis of this initial idea, and by extending the comparative study performed by M. Sabou et al. [20], we included the definitions of Intelligent Product found during our study. However, we did not find enough substantial material to produce definitions for the rest of the terms, e.g., Intelligent Object.

McFarlane et al. [41] defined an Intelligent Product as a physical and information based representation of a product. Based on [41], Kiritsis [6] summarized the properties of Intelligent Products as follows:

1. An Intelligent Product should be uniquely identified.
2. An Intelligent Product is capable of communicating effectively with its environment.
3. An Intelligent Product retains or stores data about itself.
4. An Intelligent Product deploys a language to display its features, production requirements, etc.
5. An Intelligent Product is capable of participating in or making decisions relevant to its own destiny.

According to Kärkkäinen et al. [42], the fundamental idea behind an Intelligent Product is the inside-out control of the supply chain deliverables and of the products during their lifecycle. In other words, the product individuals in the supply chain are in control of where they are going and how they should be handled. Kiritsis [6] summarized Kärkkäinen's contribution about the properties Intelligent Products should have as follows:

1. They will have a globally unique identification code.
2. They will have links to information sources about the product across organizational borders. These links will be either included in the identification code itself or accessible by some look-up mechanism.
3. They will be able to communicate tasks that need to be done on them to information systems and users when needed (even pro-actively).

Furthermore, Ventä [43] refers to intelligence as products and systems that have the following properties:

1. "Continuously monitor their status and environment."
2. "React and adapt to environmental and operational conditions."
3. "Maintain optimal performance in variable circumstances, and in exceptional cases."
4. "Actively communicate with the user, environment, or other products and systems."

Based on these definitions of Smart Product and Intelligent Product, the classification shown in Table VII was established.

The most widely used definitions are Mühlhäuser's Smart Product definition (23%) and McFarlane et al.'s Intelligent Product definition (27%). As shown in Table VII, most of the authors **do not provide** a definition. This demonstrates the need for a consensus definition.

[3] http://www.smartproducts-project.eu/ accessed January 10th, 2013.

TABLE VII. SMART PRODUCT DEFINITION STUDIES

Definition	Number	Percent
Maass & Janzen	5	19
Mühlhäuser	6	23
SmartProducts Consortium	2	8
McFarlane et al.	7	27
Kärkkäinen et al.	3	12
Ventä	2	8
Own definition	5	19
Not stated	9	35

Within these definitions, there are three categories:

1. Those referring to Smart Products. In this category, we can use the comparison presented by M. Sabou et al. [20] as a starting point.
2. Those referring to Intelligent Products.
3. Those that do not provide a definition. These may correspond either to Smart or Intelligent Products.

To establish a relationship between the proposed definitions, we needed to define the different contexts in which the authors apply the Smart Product or Intelligent Product definitions. To simplify the data synthesis and to obtain conclusive results, we considered only those articles that referred to any of the leading authors selected in the study.

Table VIII summarizes the number of studies in each context.

- Design: this includes all studies that focus on the design of new products, such as the design process and the design of human-machine or machine-machine interfaces.
- Internet of Things—IoT: this includes all studies that focus on IoT or that are concerned with object networks and their Internet and services communication.
- Product Lifecycle Management—PLM: this includes all studies that focus on the entire lifecycle of a product from its conception, through its design and manufacturing, to service and disposal.
- Ambient Intelligence—AmI: this includes all studies that focus on ambient intelligence, are from an environmental point of view, and deal with objects that have communication and computation capacity.

TABLE VIII. STUDIES BY CONTEXT

Context	Number	Percentage
Design	8	31
Internet of Things	4	15
Product Lifecycle Management	6	23
Ambient Intelligence	6	23

In Figure 1, we can see that there is a trend among Smart Product authors towards addressing issues related to design, while Intelligent Product authors are more focused on PLM. Except in the design context, one can use either a Smart Product definition or an Intelligent Product definition. In Figure 2 we can see the application context for the different authors' definitions. Except in the case of Mühlhäuser [8], which is related to design, the numbers are not significant.

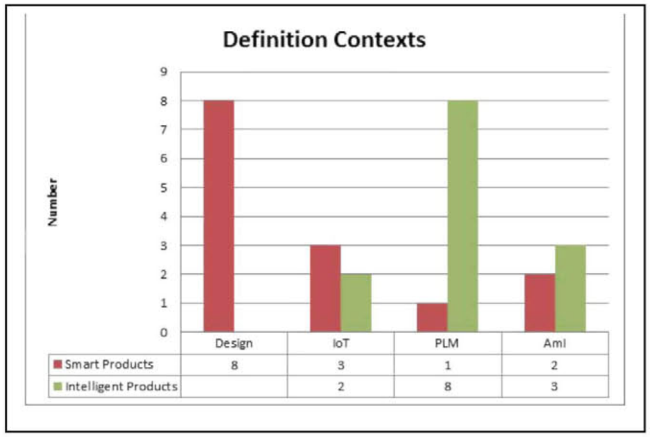

Fig. 1. Definition contexts distribution.

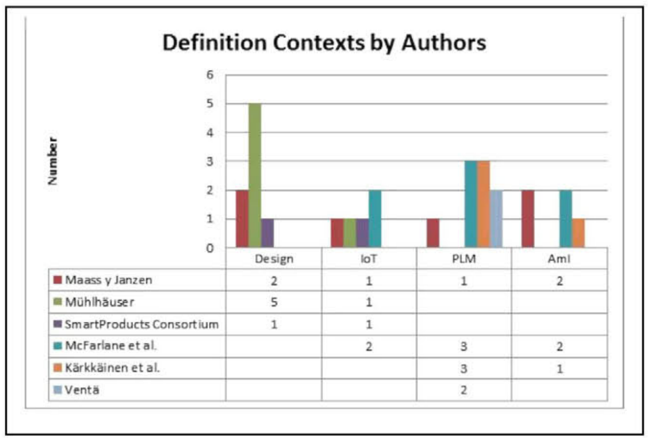

Fig. 2. Definition contexts by author distribution.

IV. ELEMENTS FOR THE DEFINITION OF SMART PRODUCTS

From Section III, it can be concluded that Smart Product and Intelligent Product can be seen as concepts that derive from a common root, and that somehow have become specialized. To model this fact, the "Smart Thing" concept was introduced. Figure 3 is a (meta)model in which Smart Thing becomes specialized within Smart Product and Intelligent Product. Smart Thing can be defined as a product or object that responds to some of the collected definitions of Smart Products and Intelligent Products.

Different authors provide different features for Smart Products. It may be useful to create a model that considers all of these characteristics; this model plays the role of an ontology in practice. Figure 4 extends the ontology for the definition of a Smart Thing as specified in Figure 3. This has been created on the basis of the features provided by the different authors in both their Smart Product definitions and their Intelligent Product definitions. This extended ontology shows that there are several complementary definitions for the concept of Smart Thing, whether in terms of Smart Product or Intelligent Product. In order to be considered a Smart Thing, a product must meet certain requirements. As we can see, some of these are recurring features. These features are considered to be the most characteristic.

The application of context in the definitions of Smart Thing (Figure 5) has also been defined, extending Figure 3's ontological model. Figure 5 shows the application of the definitions in the different contexts in which they are applied. This can help to make the right selection of the definition based on the context in which the product will operate.

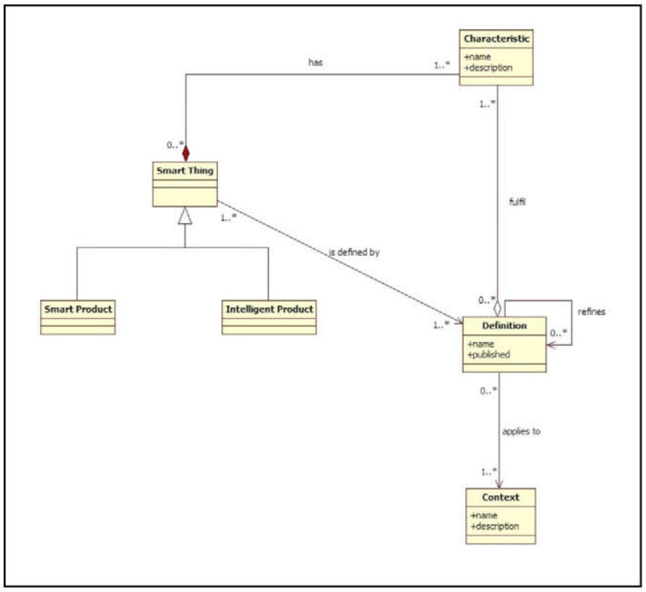

Fig. 3. Metamodel for the definition of "Smart Thing."

V. LIMITATIONS OF THE STUDY

The main limitation of the literature review is bias in the data extraction, since it was a manual process and much of the information collected was implicit data. However, we believe that because of the limited number of primary studies, the data extraction process was done objectively.

Due to the use of a meta-search engine to locate the studies, some relevant studies could have been missed. However, this risk is minimized, since those studies could have been cited in one of the identified studies. Basically, our results contain only those studies published in the major international software engineering journals or workshops supported by the meta-search engine used by us.

VI. CONCLUSIONS

This paper presents the results of a systematic literature review of Smart Products. This study's contribution is the investigation and identification of the different definitions that most researchers are currently using to talk about these kinds of products. The objective was to reach a consensus definition for Smart Product.

In this systematic review, 26 studies between 2008 and 2012 were analyzed. These studies included the characteristics, needs, and quality required in order to answer the proposed research question.

The present work concludes that it is possible to reach a consensus definition for Smart Product in the domain of software and systems engineering, and this definition is provided as an ontology. Some alternative terms to Smart Product, such as Intelligent Product, are also used. Therefore, it is necessary to introduce an umbrella term, Smart Thing, so that Smart Product and Intelligent Product are modeled as specializations of Smart Thing. Though different authors provide definitions, these definitions overlap considerably, and where they do not, they are compatible. The obtained ontology includes Smart Product characteristics, and these characteristics are related to its use in different contexts.

This definition can be used to build a design theory, as well as a quality model, and it is a starting point for further research on areas such as Software Ecosystems, the Internet of Things, Autonomic Computing, Ambient Intelligence, Smart Cities, and Smart Grids. All of these areas are not disjointed sets; they overlap. The concept of a Smart City is currently under development, and it will give way to the development of complex digital ecosystems. The potential for all of these areas is high, and they will accommodate many different Smart Products.

However, one of the conclusions of this research is that Smart Product studies have stagnated in recent months. This might be problematic for various reasons:

- The issue cannot and must not be considered closed.
- Smart Products have a number of characteristics distinguishing them from other products, besides being a strategic point during innovation.
- Dispersion is large around the Smart Product concept.

As a result, Smart Product could end up as just another buzzword, and a new one could replace it. This would not help the engineering of computer based systems at all. One way to face this challenge would be to submit current definitions for standardization. We plan to follow this path. We also envisage systematizing the specification and design of Smart Products. The definition provided within this paper is an excellent starting point.

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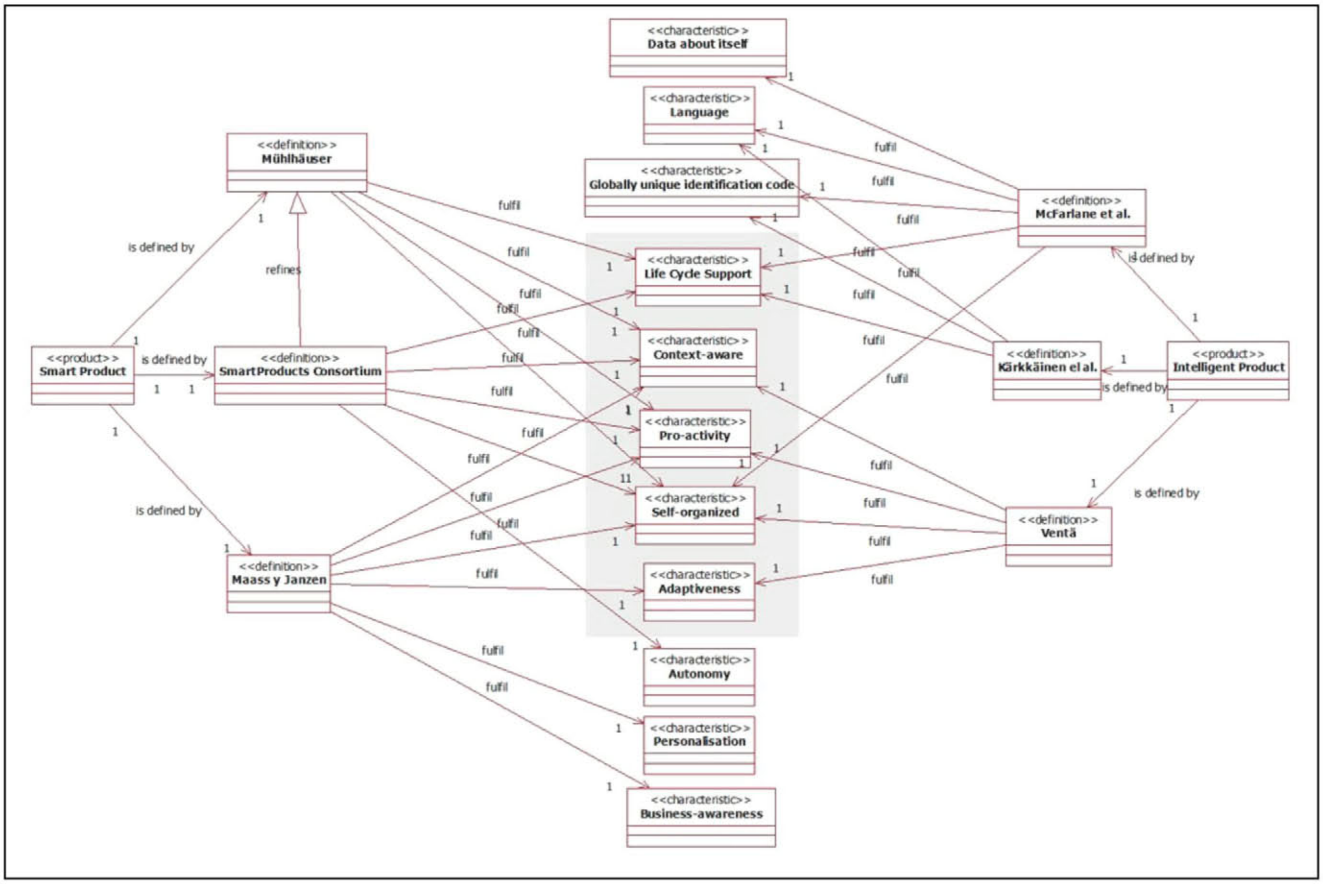

Fig. 4. Subontology for the definition of “Smart Thing.”

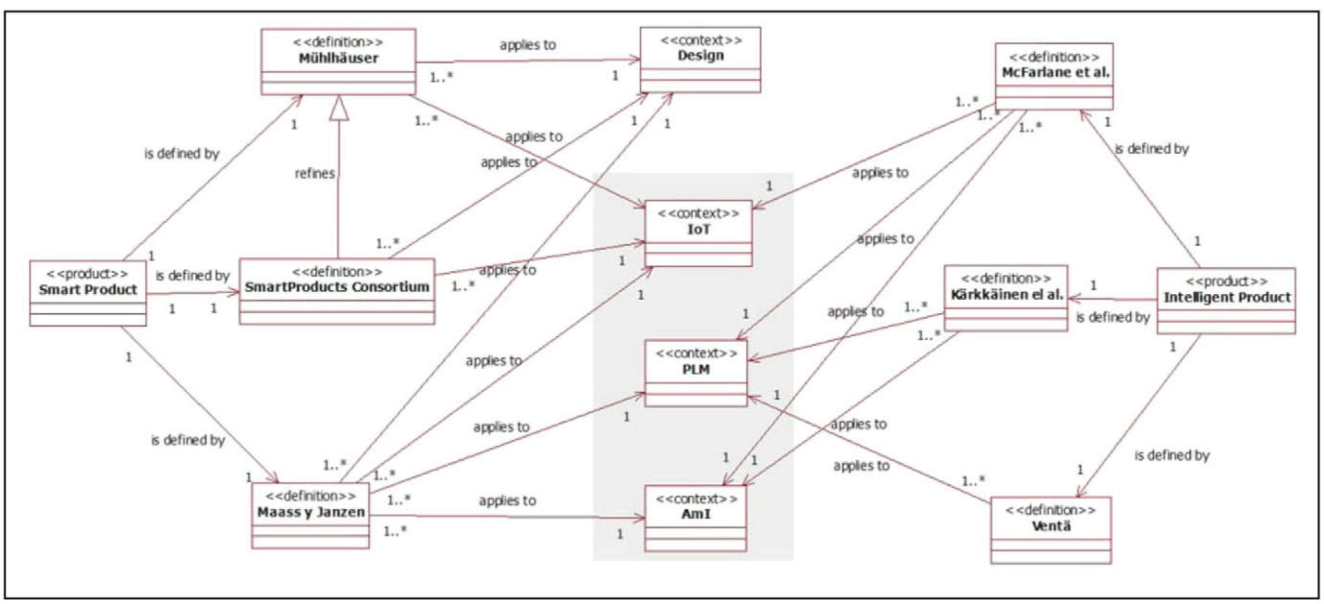

Fig. 5. Subontology for the application of context in the definitions of “Smart Thing.”

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