Article

Design Thinking Applied to Smart Home Projects: A User-Centric and Sustainable Perspective

Flavio Martins, Maria Fatima Almeida *, Rodrigo Calili * and Agatha Oliveira

Technical Scientific Center, Pontifical Catholic University of Rio de Janeiro, Rio de Janeiro 22453-900, Brazil; flavio.martins@enel.com (F.M.); agathatommasi@gmail.com (A.O.)
* Correspondence: fatima.ludovico@puc-rio.br (M.F.A.); calili@puc-rio.br (R.C.)

Received: 1 November 2020; Accepted: 22 November 2020; Published: 1 December 2020

Abstract: This paper aims to propose a conceptual model to create and select smart home conceptions from the user-centric and sustainable perspective, using the Design Thinking approach. Although considerable research has been devoted to smart homes in the last two decades, gaps are evident in current research concerning the creation and selection of smart home conceptions from both user-centric and sustainable perspectives. A systematic literature review covering the period 2000–2020 indicated that Design Thinking (DT) has rarely been exploited in smart home projects. The applicability of the proposed model could be demonstrated in the context of a smart home project in Brazil (NO.V.A. Project) conducted by an energy distribution player in this country in cooperation with two local universities and other institutional partners. The replication of this approach in smart home projects will allow decision-makers and project managers to place future residents at the center of the smart home design, creating and selecting the best conceptions that will meet users’ desires, expectations, and needs that can be transformed into reality.

Keywords: smart home; user-centricity; sustainability; design thinking; crowdsourcing; morphological analysis; multicriteria decision-making methods

1. Introduction

By introducing automated appliance control, comfort, safety, and assistive services, smart homes can provide a better quality of life. Smart home technologies (SHTs) include monitors, interfaces, sensors, appliances, and devices networked to make automation possible as well as remote control of the domestic environment. Despite their numerous potential benefits, there are substantial gaps in the existing knowledge on the design of smart homes that bring user-centric and sustainable visions together. These gaps have been highlighted in the majority of relevant studies. The literature predominantly focuses on the technical characteristics of smart homes (e.g., [1–6]), which means that there is a need for the adoption of the user perspective in research on SHTs’ development [7].

Most of the studies that employed user-centric vision have focused on the aging and disabled users’ needs, while disregarding other user segments (e.g., [8–15]). The move from technology-driven research towards a user-centric approach has enabled researchers and designers to explore the potential development of a broader scope of services to fulfill more user segments and encompass all the potential benefits of SHTs (e.g., [16]).

In view of the aforementioned context, current studies have attempted to examine users’ perceptions towards specific technologies and services, which creates another widely discussed prospect to be addressed in future research. To illustrate, some previous works have investigated users’ needs or the user-friendliness and the perception of values of single devices instead of analyzing smart homes as a whole (e.g., [17–19]).
Moreover, another important debate has been raised in recent years regarding two different design visions for smart home projects. The first views a desired smart home as a home that enhances people’s experiences of comfort, entertainment, safety, and security through pervasive technologies [20–22]. The second involves the progressive search to design sustainable smart homes [23–26]. In most smart home research, these visions have been addressed separately and could potentially weaken each other. Recent works have shown that the quest for desirable smart home designs may increase consumption and exceed energy efficiency benefits [22,23].

In this paper, we approach this emerging dilemma by bringing user-centric and sustainable perspectives together to explore ways of conducting everyday life towards comfort and entertainment, safety, and security, the efficient use of natural and energy resources, and the adoption of technological innovations embedded in a smart sustainable building.

The Design Thinking (DT) approach, which was conceived for product design through a strong emphasis on user-centricity, consumer empathy, and rapid prototyping [27,28], has developed new applications beyond new product design and grown its popularity to support problem solving for broader level challenges [29–31].

A systematic literature review covering the last two decades pointed out that the DT approach has rarely been exploited in smart home projects [8,32,33]. Besides the scarce use of this methodological approach, another concern for providing user-centric and sustainable conceptions for evidence-based decisions is how to apply and combine different theoretical approaches and tools with the DT approach.

At the same time, it is worth noting that:

- Smart home technologies have the potential of bringing benefits to modern households and residents. Smart home projects have aroused great interest from researchers worldwide, and several experiences of smart homes as living labs have demonstrated the numerous positive effects they provide to their residents [25,34–36];
- As smart home development has rarely been primarily concerned with environmental impacts, it can create a demand for modern energy services that adds to the inventory of climate and habitat damage [37–40];
- Complexity and multidisciplinarity are characteristics inherent to the creation and selection of new conceptions for smart homes based on new technological solutions [41];
- Multicriteria decision-making methods (MCDM) and other managerial tools can be integrated into a DT process, incorporating and refining the good practices that have been adopted until now in smart homes designs;
- The NO.V.A. Project (in Portuguese, the acronym for the expression “We Live the Tomorrow”), conducted by a private player in energy distribution in Brazil, offered a rich multistakeholder environment to demonstrate the applicability of a conceptual model developed from a user-centric and sustainable perspective.

From the literature review and documentary analysis covering the 2000–2020 period, the following research gaps were identified:

- Most of the studies that employed a user-centric vision have focused on the aging and disabled users’ needs while disregarding other user segments (e.g., [8–15]);
- In most smart home research, the user-centric and sustainable perspectives have been addressed separately and potentially weaken each other [20–26];
- The potential for applying the Design Thinking approach has rarely been exploited in smart home projects [8,32,33];
- A crowdsourcing model and MCDM combined with Design Thinking have not yet been explored in smart home projects.

Based on these gaps, the following research questions were posed:
What is the best way to create and select smart home conceptions from a user-centric and sustainable perspective?

To what extent would the application of a user-centric and sustainable conceptual model that combines DT approach with morphological analysis, crowdsourcing, and MCDM methods help organizations to create and select the best smart home conceptions?

Therefore, this paper aims to propose a conceptual model to create and select smart home conceptions from a user-centric and sustainable perspective, using the DT approach combined with morphological analysis, crowdsourcing, and MCDM methods.

The article is structured in six sections. Following the introduction, the second section details the adopted methodology. In the third section, the conceptual model is proposed, highlighting the empathic, user-centric, and sustainability emphases for smart home projects.

The fourth section demonstrates the applicability of the proposed model through an empirical study in the context of a smart home project in Brazil, developed by a private player in energy distribution in Brazil in cooperation with two local universities. The empirical results and managerial implications are discussed in the fifth section in light of the DT theoretical background and the previous smart home models identified during the literature review and documentary analysis. Finally, the last section synthesizes the conclusions and suggestions for replicating the proposed conceptual model throughout smart home projects.

2. Methodology

The research methodology encompasses four phases and six stages, following a procedural model based on Oliveira et al. [42] to provide an underlying structure and an approved course of action for this research. In this section, the selected research methods are described to address the questions posed in Table 1.

Accordingly, the research phases are: (i) motivation; (ii) conceptualization and development; and (iii) validation.

Aligned with these three phases, the stages described in Table 1 refer to the problem definition and the rationale for the research (first stage); state of research on central themes, and identification of research gaps and unsolved problems in the focused field (second stage); definition of the research methodology (third stage); development of the conceptual model to generate and select user-centric and sustainable smart home conceptions based on the Design Thinking approach (fourth stage); application of the conceptual model in the context of a smart home project in Brazil (fifth stage); and discussion of the empirical results and implications for decision-makers and experts responsible for the coordination and development of smart home projects (sixth stage).

The two first stages covered a literature review and documentary analysis on the research themes by accessing the main sources of peer-reviewed scientific articles, such as Scopus; Web of Science; Science Direct; and other sources, from the period 2000 to 2020. In addition, a Google Scholar search complemented the first set of results. Moreover, a backward search based on references cited in the chosen documents was integrated with this analysis. After this review, the importance of developing a conceptual model for user-centric and sustainable smart home projects based on the DT approach could be evidenced, and research gaps were objectively identified. During the third stage, the research methodology was defined and detailed.

From the literature review and documentary analysis, the Design Thinking approach [27–31] was chosen to develop a conceptual model addressed to create and select user-centric and sustainable smart home conceptions.

The resulting model combines crowdsourcing [43–48], general morphological analysis (GMA) [49–53], and two multicriteria decision-making methods, namely the Analytic Hierarchy Process (AHP) [54,55] and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [56].
Table 1. Research design.

| Phase                        | Stage                                                                 | Research Question                                                                                     | Section |
|------------------------------|----------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|---------|
| Motivation (Why?)            | Problem definition and the rationale for the research                | Why should we develop a conceptual model to generate and select user-centric and sustainable smart home conceptions based on the Design Thinking (DT) approach? |         |
| Conceptualization and        | State of research on central themes and identification of research gaps and unsolved problems in the focused field | Which are the substantial gaps in the existing knowledge on the design of smart homes that bring user-centric and sustainable visions together? | Section 1 |
| development (What and How?)  | Definition of the research methodology                               | How could a user-centric and sustainable conceptual model approach be developed and validated?         |         |
| Validation                   | Development of the user-centric and sustainable conceptual model     | How can DT be combined with crowdsourcing, morphological analysis, and multicriteria decision making methods to fill the substantial research gaps identified in Section 1? | Section 3 |
|                              | Application of the conceptual model in the context of a smart home project in Brazil, developed by a private player in energy distribution in this country. | What were the results generated in the immersion phase of the smart home project?                      | Section 4 |
|                              |                                                                     | What were the results obtained in the analysis/synthesis? Which are the archetypes identified as future residents of smart homes (personas)? |         |
|                              |                                                                     | Which were the selection criteria defined for choosing the best smart home design from a user-centric and sustainable perspective? |         |
|                              |                                                                     | Also, what are the results of the ideation and prototyping phases? What was the best smart home conception chosen? |         |
|                              | Discussion of the empirical results and implications of the adoption of the model in others smart home projects from the user-centric perspective. | Could the results of the NO.V.A. Project in Brazil demonstrate the applicability of the proposed model? |         |
|                              |                                                                     | What are the main differentials of the proposed model concerning the methodological approaches covered by the literature review? |         |
|                              |                                                                     | Which are the managerial implications of this research?                                               |         |

Source: Based on Oliveira et al. [42].

Crowdsourcing is a sourcing model in which individuals or organizations obtain ideas, voting, and tasks, from a large and rapidly evolving group of participants. With crowdsourcing, design activities conventionally carried out by a nominated team are outsourced to a large group of people in the form of an open call. In this research, a crowdsourcing platform was created to collect more comprehensive views from people across the world. By way of illustration, during the immersion phase of the NO.V.A. Project in Brazil, around 16 million people were reached, 47,000 users accessed the crowdsourcing platform, and 5500 people participated and generated 4600 ideas. These ideas were evaluated by focus groups, with the best ones incorporated into consistent and plausible conceptions during the ideation phase.

General morphological analysis (GMA) aims to identify, structure, and investigate the total of possible relationships in a given multidimensional and complex problem. Adopting the cross-consistency assessment technique, one can identify the possible solutions that exist, eliminating the unreasoned solution combinations rather than reducing the number of parameters involved. This methodological approach has been applied successfully in strategic planning, engineering design, technological and business foresight, organizational development, and policymaking [57,58]. For this research, GMA was...
particularly helpful to analyze and visually represent alternative technological conceptions for smart home projects. Therefore, a generic morphological matrix was designed based on eight parameters: (i) entertainment and comfort; (ii) home automation; (iii) remote access; (iv) network and information security; (v) healthcare services; (vi) efficient use of natural resources; (vii) energy resources and management; and (viii) surveillance and property security. Consistent alternative conceptions for smart homes (associated with different embedded technologies and home services) could be created from a user-centric and sustainable perspective.

Combined with GMA, a hybrid multicriteria decision-making method (AHP-TOPSIS) was used for: (i) defining selection criteria aligned with the smart home project’s guiding assumptions; and (ii) ranking alternatives and selecting the best smart home conception that met both the criteria and the future residents’ expectations and needs.

The Analytical Hierarchy Process (AHP) method, created by Saaty in 1980 [54,55], was adopted during the modeling phase for weighting the selection criteria. The second method, Technique for Order Performance by Similarity to Ideal Solution (TOPSIS), developed by Hwang and Yoon in 1981 [56], was used to rank and select alternative smart home conceptions. Due to the interdisciplinary nature of smart home projects, this hybrid method’s application required individual experts representing various professions and disciplines besides one’s own interdisciplinary research team.

Finally, the conceptual model’s applicability could be demonstrated in the context of a smart home project in Brazil, developed by a private player in energy distribution in this country in cooperation with two local universities. This empirical study followed Yin’s methodological approach [59] to understand how organizations aiming to implement smart home projects can better design consistent alternative conceptions and select the best ones in alignment with each project’s guiding assumptions.

3. Design Thinking Applied to Smart Home Projects: Proposal of a Conceptual Model from a User-Centric and Sustainable Perspective

In this section, we propose a conceptual model to create and select user-centric and sustainable smart home conceptions, based on a DT methodological approach (Figure 1).

Figure 1. General view of a conceptual model from a user-centric and sustainable perspective.

As shown in Figure 1, the conceptual model follows the DT approach and comprises four phases, namely: (i) immersion that is carried out in two stages (preliminary immersion and immersion in depth); (ii) analysis and synthesis encompassing focal groups’ analysis; creation of archetypes of future residents of the smart home, and definition of selection criteria aligned with the guiding assumptions of the smart home project; (iii) ideation including the use of the GMA for generating alternative consistent smart home conceptions and the adoption of a hybrid MCDM for selecting the best alternatives;
and (iv) the prototyping phase, focusing on the NO.V.A. Project in Brazil (in Portuguese, NO.V.A. is the acronym of the expression “We Live the Tomorrow”). The following items describe each phase of the proposed framework in detail.

3.1. Phase I: Immersion

The immersion phase comprises two stages: (i) preliminary immersion and (ii) deep immersion.

3.1.1. Preliminary Immersion: Exploratory Research and Alignment Meetings with Stakeholders and Experts

During the first stage of the immersion phase, the DT Project Team should review the scientific literature and carry out a documentary analysis on existing smart home models and projects around the world. In parallel with this desk research, exploratory field research with groups of typical residents of the future smart home should be conducted with the support of project stakeholders (contractors, experts, and other interested parties). In this stage, strategic alignment meetings should be held involving the whole DT Project Team and representatives of the project stakeholders. The main objective of the alignment meetings is to reframe the initial DT problem from different perspectives. Concerning this, the DT Project Team should present a general picture of the future smart home’s service categories and respective functions associated with each service. In that context, frameworks and taxonomies of smart home services and functions, proposed by some authors (e.g., [6,20,21,60–63]) can be a starting point to draw such a general picture.

3.1.2. Deep Immersion: Application of a Crowdsourcing Model and Generative Sessions

To hear as many people as possible about how they imagined living in a smart home, during the deep immersion stage, a crowdsourcing platform should be created and implemented. Within a crowdsourcing model, design activities conventionally carried out by a nominated team are outsourced to a large group of people in the form of an open call. The crowdsourcing platform should be structured based on the main categories of services offered by a smart home, as well as the expectations and needs of future residents previously identified during the strategic alignment meetings.

On a digital collaboration platform, all people interested in discussing topics related to the smart home project can register and post their needs, expectations, and ideas about what the smart home should look like. Some sample questions that can be raised on this platform are: “What categories of services and features should offer the future smart home?”, and “what innovative technological solutions can be installed in a smart home?”

This method consists of a model of collaboration (participation) or problem-solving, which takes place online through a Web platform [43–48,51]. In a crowdsourcing process, the challenges are communicated in the form of an open call, and the participants submit ideas and solutions according to a structured frame based on the categories of services and functions that should be provided by the future smart home. In some cases, the proponent of a given solution is compensated with prizes or with financial recognition. In other cases, the only rewards can be praise or intellectual satisfaction.

In parallel to the crowdsourcing process, generative sessions were proposed for this stage [64,65]. During these meetings, the actors directly involved in the project, invited experts, and typical future residents can share their experiences and expose their points-of-view on the categories of services and desired and reliable functions for the future smart home.

3.2. Phase II: Analysis/Synthesis

In the analysis and synthesis phase, it is recommended to use innovation management and marketing methods and techniques, such as those suggested by Ideo [64] and Stanford d.school [65], aimed at classifying and analyzing the information collected in the crowdsourcing process. These techniques include affinity diagrams, concept maps by category of services, and a general concept map with all categories.
3.2.1. Focus Group Discussion

For this phase, it is recommended to create focus groups to obtain future residents’ perceptions vis-à-vis experts’ opinions concerning technological innovations that could be embedded in the smart home [66,67]. First of all, the DT Project Team should define the research objectives and key simple research topics (by category of services to be offered by the smart home). Based upon the research objectives and topics, a list of questions was prepared as guidance for each focus group discussion session. Participant identification and invitation was the most critical step, since the technique is basically founded on group dynamics and synergistic relationships among participants to generate data. Another important concern is the number of respondents to be invited for discussion sessions. Some authors have recommended a maximum of 10 participants per focus group [66,67].

Focus group discussion requires a team consisting of a skilled facilitator and an assistant. The facilitator is central to the discussion not only by managing existing relationships but also by creating a favorable environment for open discussions. Similarly, the assistant’s role includes observing non-verbal interactions and the impact of the group dynamics and documenting the general content of the discussion, thereby supplementing the data [64–67].

3.2.2. Identification of Archetypes of Future Residents

As a complement to the future residents’ perceptions vis-à-vis technological innovations to be considered in smart home conceptions, the DT Project Team should identify archetypes of future residents of the smart home (also called personas), which represent motivations, desires, expectations, and needs, revealing significant characteristics of a more comprehensive group. Personas are fictional representations of future smart home residents and are based on real data about these people’s demographic characteristics and behaviors.

This concept was created by Alan Cooper in 1999, who recommends using a combined approach of constructing persons and goal-directed design [68]. This approach will help the DT Project Team focus on the right users and their needs and aspirations, including personal goals that can influence the use.

According to Cooper et al. [69], the constructing process comprises seven steps: (i) identify behavioral variables; (ii) map interview subjects to behavioral variables; (iii) identify significant behavior patterns; (iv) synthesize characteristics and relevant goals; (v) check for completeness and redundancy; (vi) expand the description of attributes and behaviors; (vii) designate persona types.

After designating persona types, the DT Project Team must identify for each persona: (i) attitudes, experiences, aspirations, and other social, cultural, environmental, and cognitive factors that influence the persona’s expectations; (ii) general expectations and desires that the persona may have about the experience of living in a smart home; and (iii) how that persona thinks about essential elements and technologies that will be embedded in a smart home [69].

The recommended tools are surveys, questionnaires, and interviews and workshops with the target audience (s) for creating personas and identifying their expectations and desires [70,71]. In this model, the collection of qualitative and quantitative data let the DT Project Team form an objective image of the ideal types of smart home residents, emphasizing what they put a value on and what solutions are most suitable for them.

3.2.3. Definition of Selection Criteria for Choosing the Best Smart Home Conception

The definition of selection criteria for the next phase—ideation—needs to be totally aligned with the strategic guidelines of the smart home project, highlighting aspects that should not be neglected throughout all stages of ideation and prototyping. These aspects arise from analysis of the data collected in the interviews to create the personas, from synthesis of results from the crowdsourcing process, and from the objective and scope defined for the project, in addition to directions suggested in the generative sessions. They serve as a basis for determining the limits of the project from a
user-centric and sustainable perspective. For example, if the design of a smart home is intended to meet the needs of an elderly audience, then the project should provide the installation of assistive and telemedicine technologies. Once a multicriteria decision-making approach is adopted in the ideation phase, it is recommended for this step to assess the selection criteria for smart home projects developed by Wong and Li [60].

The selection criteria should always be present during the generation of smart home conceptions once they parameterize and guide the choice of technological innovations for the smart home, evidencing its adequacy to the scope and principles of the project. These criteria emerge from the systematization of the immersion phase’s data during the construction of a diagram affinities or a concept map. Accordingly, no relevant information or claims will be neglected, and the technological innovations’ choice will meet the guiding criteria and the personas’ needs and expectations.

3.3. Phase III: Ideation

The main purpose of the ideation phase is to create alternative smart homes conceptions, which come to meet the selection criteria and persona’s aspirations that were defined in the previous phase. It was proposed for the ideation phase to combine general morphological analysis (GMA) [50–53] and a hybrid multicriteria decision-making method, which integrates Analytic Hierarchy Process (AHP) [54,55] and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [56].

3.3.1. Creation of Alternative Smart Home Conceptions: Use of General Morphological Analysis (GMA)

GMA is an analytical-combinatorial technique, which is based on the decomposition of a problem, or object of analysis, in its attributes. It aims at identifying, structuring, and investigating the total set of possible relationships contained in a given multidimensional and complex problem. Adopting the technique of cross-consistency assessment, one can identify the possible solutions that actually exist, eliminating the unreasoned solution combinations rather than reducing the number of parameters involved [50–53]. GMA has been applied successfully in engineering design, strategic planning, technological and business foresight, organizational development, and policymaking [57,58].

Created by Zwicky [50], GMA is a method for identifying and investigating the whole set of possible relationships in any given, multidimensional, and complex problem that can be parameterized. The logic of problem decomposition is to deal with less complex issues than the original system (the smart home as a whole), thus enabling a deeper analysis of the parts (categories of services and associated functions). Through systematic analysis of the possible states, one can create a universe of smart home conceptions (Figure 2).

The basic premise of choosing GMA is that a complex problem—such as a smart home project—can be broken down into fundamental variables (here, the main categories of services to be provided for future residents), which undergo a systematic analysis of the possible states that they may assume.

This method comprises five (iterative) steps, as follows: (i) formulating the research problem to be solved very concisely; (ii) identifying all parameters that might be of importance for solving the problem; (iii) constructing the morphological matrix, which contains all parameters and their possible states; (iv) evaluating the consistency of possible morphological conceptions in relation to the purpose to be achieved; and (v) defining and choosing consistent conceptions of suitable solutions.

Thus, a set of smart home technologies (SHTs) referring to each category of services can be identified and plotted in a morphological space. Figure 3 shows a plausible and consistent alternative conception generated by GMA. Smart home conceptions that are intrinsically inconsistent, unsustainable, or economically unviable are discarded. Only those conceptions that are considered to be plausible are filtered.
3.3.2. Selection of the Best Smart Home Conception: Use of the Hybrid AHP-TOPSIS Method

Once plausible and consistent alternative conceptions are generated by GMA, the DT Project Team can move on to the second stage of the ideation phase. The application of the AHP-TOPSIS method requires the participation of experts in the various disciplines referring to the project (given the multidisciplinary nature of smart home projects) and representatives of the project’s stakeholders.

The AHP method should be adopted to define the weights of the selection criteria and the TOPSIS technique to rank the alternative conceptions and select the best one. The application of this method follows this sequence of steps: (i) organization of the hierarchical structure, through the identification of the main focus, criteria, and subcriteria; (ii) data acquisition concerning the value judgments from experts, through the pairwise comparison of criteria; (iii) establishment of the pairwise comparison matrix including the calculation of Consistency Ratio, that is calculated by dividing the Consistency Index for the set of judgments by the Index for the corresponding random matrix.
The scale to be adopted here is the nine-pointed scale proposed by Saaty [54,55], as shown in Table 2.

| Level of Importance | Definition                                      |
|---------------------|------------------------------------------------|
| 1                   | Same importance                                |
| 2                   | Preference between the same and moderate       |
| 3                   | Moderate preference                            |
| 4                   | Preference between moderate and strong         |
| 5                   | Strong preference                              |
| 6                   | Preference between strong and very strong      |
| 7                   | Very strong preference                         |
| 8                   | Preference between very strong and absolute    |
| 9                   | Absolute preference                            |

Saaty suggests that if that ratio exceeds 0.1, then the set of judgments may be too inconsistent to be reliable. If a matrix is inconsistent, then new pairwise comparison judgments are required, as well as calculation of the weights of the selection criteria.

Once the inconsistency ratio is accepted, it is possible to calculate the weights of criteria, following the procedure described by Saaty [54,55] and using the SuperDecisions® software [72,73].

With the weighted selection criteria, the next steps are ranking the alternative conceptions and choosing the best one for the project in focus. Here, the TOPSIS method was chosen for ranking and selecting the smart home conceptions created in the first stage of the ideation phase. The scale to be adopted in this phase ranges from 1 to 5 was defined as follows: (i) score 1—the conception does not meet the criteria/subcriteria; (ii) score 3—the conception moderately meets the criteria/subcriteria; (iii) score 5—the conception fully meets the criteria/subcriteria. Scores 2 and 4 refer to the intermediate values of the scale.

This method comprises five steps, as follows: (i) experts make consensual judgments concerning the performance of alternative smart home conceptions in light of each criterion; (ii) identify the positive ideal solutions A+ (benefits) and A- (costs); (iii) calculate the Euclidean distances from the Positive Ideal Solution (PIS) and the Negative Ideal Solution (NIS) of each alternative conception; (iv) calculate the closeness coefficient of each alternative concerning PIS; and (v) the ranking order of all alternative conceptions for selecting the best one.

The best alternatives are those that have the higher Closeness Coefficient (CCi) values, i.e., they are closer to the PIS. All the formulas and parameters used in this procedure can be found in Hwang and Yoon [56].

The final decision on which conception should be chosen among the best alternatives must consider the future residents’ needs and aspirations to evaluate the acceptance of the target audience(s) regarding each of those alternatives. The one most adherent to the personas’ needs and aspirations will be indicated to be implemented.

3.4. Phase IV: Prototyping

In this phase, the expansion of the concept space results in the ideas materialization associated with the smart home conception in order to represent the captured reality and provide the validation of all detained contents.

Prototyping is carried out according to: (i) the internal perspective (DT Project Team and institutional partners); and (ii) the context perspective (project stakeholders and users). After the internal validation of the selected smart home conception, according to the DT Project Team’s
In this model, the suggestion for the prototyping phase is an architectural the pre-design in which much of the work does not really involve the production of the project document per se. The morphological matrix provides the basic ideas of what the smart home should look like and how it should function. In the pre-design phase, the architect must work closely with the DT Project Team to define and clarify the basic ideas. This is commonly done with the use of a tool called programming. It is suggested to include in the programming stage a virtual mockup that allows the observer to see and modify the future project and to interact with it, modifying its characteristics. Also, a virtual tour video of the selected smart home conception can complement the virtual mockup.

4. Empirical Validation of the Conceptual Model in a Smart Home Project in Brazil

The applicability of the conceptual model could be demonstrated in the context of a smart home project in Brazil (NO.V.A. Project), developed by a private player in energy distribution in this country (Enel Distribuidora Rio) in cooperation with two local universities: Pontifical Catholic University of Rio de Janeiro (PUC-Rio) and Getúlio Vargas Foundation (FGV).

4.1. Context and Objectives of the NO.V.A. Project in Brazil

The NO.V.A. Project (NO.V.A. is an acronym in Portuguese for the expression “We Live the Tomorrow”) is an initiative within the set of R&D projects of the Enel Group in Brazil, developed with the endorsement of the Brazilian National Electric Energy Agency (Aneel).

Under the leadership of Enel Distribuição Rio, the NO.V.A. Project was carried out in partnership with the Niteroi Town Hall, the Pontifical Catholic University (PUC-Rio), the Getúlio Vargas Foundation (FGV) and other institutional partners.

The NO.V.A. Project aims to design a smart home, which will serve as a living laboratory for understanding the perceptions and expectations of its future residents in relation to comfort and entertainment, safety and security, automation of domestic tasks, internal mobility and healthcare, and efficient use of natural and energy resources.

The conceptual model proposed in Section 3 integrated the scope of this Project and its development benefited from a multistakeholder environment provided by Enel Distribuição Rio that were allowed to demonstrate its applicability and exploit in practice the benefits of adopting a methodological approach that could bring user-centric and sustainable visions together.

4.2. Phase I: Immersion

As described in Section 3, this stage comprised two phases: (i) preliminary immersion; and (ii) deep immersion, which encompasses a crowdsourcing process and a series of generative sessions.

4.2.1. Preliminary Immersion: Exploratory Research and Alignment Meetings with Stakeholders and Experts

During the first stage of the immersion phase, the Project Team developed a literature review and documentary analysis on smart home models and experiences in other countries. The Pontifical Catholic University of Rio de Janeiro (PUC-Rio) and the Getúlio Vargas Foundation (FGV), partners of the Project, mapped the most innovative technological solutions for smart homes to highlight the most strategic options to be considered in the ideation phase of the Project.

In parallel with this desk research, four alignment meetings were held to bring the Project Team, partners, and stakeholders together to align expectations and previous experiences with the objectives of the Project. Concomitantly, workshops (called 'meet-ups') were held with the participation of invited opinion formers, academics, and representatives of diverse segments of society. These meetings were intended for exposing and discuss daily life themes, social trends, and future perspectives. Moreover, it was developed a warm-up phase, with campaigns through the NO.V.A. Facebook page, aiming to
prepare the public for the most open dialogue phase that was later implemented in the deep immersion stage—the crowdsourcing process.

4.2.2. Deep Immersion: Application of a Crowdsourcing Model and Generative Sessions

During the deep immersion, a crowdsourcing platform was created, aiming to hear from as many people as possible about how they imagined living in a smart home would be. The registered participants on the website were asked to include an idea to answer the following question: “If you could start building the house today that will you live in by 2040, what would it be like?”. To complete the submission of the idea, in addition to including a title and the idea content, participants were still asked to categorize their ideas into one of the following categories: (i) comfort and entertainment; (ii) home automation; (iii) remote access; (iv) network and information security; (v) healthcare services; (vi) efficient use of natural resources; (vii) energy resources and management; and (viii) surveillance and property security.

Concerning the engagement dynamics in the collaborative digital platform, a gamification strategy was implemented and the participant who had the largest amount of interactions was rewarded with a trip to Italy to participate in the Milan Design Week.

During the crowdsourcing process, several generative sessions took place. The NO.V.A Project Team and partners shared their experiences and carried out activities in which they could present their views on the categories of services and functions for the future smart home. As a result of the deep immersion phase, around 16 million people were reached, 47,000 users accessed the crowdsourcing platform, while 5500 people participated and generated 4600 ideas. These ideas were evaluated by focus groups, being the best ones incorporated into consistent conceptions during the ideation phase.

4.3. Phase II: Analysis/Synthesis

In the analysis/synthesis phase, several techniques and tools suggested by Ideo [62] and Stanford d.school [63] were employed to classify and analyze the information gathered during the crowdsourcing process. These techniques include: (i) focus group discussion around the categories of smart home services and specific research topics; (ii) identification of archetypes of future residents; and (iii) definition of the selection criteria for choosing the best smart home conception for the NO.V.A. Project.

4.3.1. Focus Groups Discussion

Following the procedures described in Section 3.2.1, several focus groups were organized around the categories of smart home services and specific research topics. In these meetings, the central activity consisted of identifying the proposal of each idea and the solutions that were related to it. Then, the ideas were prioritized within each category to be considered in the ideation phase.

4.3.2. Identification of Archetypes of Future Residents

According to Section 3.2.2, a workshop was conducted by the Project Team involving marketing experts, designers, political scientists, and representatives of the target audiences. The qualitative and quantitative data collection let the Project Team form an objective image of the ideal types of future smart home residents and their expectations, needs, and aspirations. The following questions were posed during this meeting: “What would the professions, hobbies, and interests be of future residents?”; What would their likely physical characteristics, their health conditions, their talents, and their limitations be?“; “What are the general expectations and desires that future residents may have about the experience of living in a smart home?”; and “What would future residents think about basic elements and technologies that will be embedded in a smart home?”.

Thus, six personas were fictitiously created representing the future residents of the smart home object of the NO.V.A. Project, and their needs and aspirations could be identified.

Table 3 presents the representing groups of future residents (personas) of the smart home object of the NO.V.A. Project.
Table 3. ‘Personas’ representing future residents of the smart home object of the NO.V.A. Project.

| Persona | Profile and Mindset | Needs and Aspirations |
|---------|---------------------|------------------------|
| Maria   | She is 74 years old, lives alone, retired and is a former hard working and active entrepreneur. She is concerned about sustainability. She has special health needs. She believes that after an intense life, many people of her generation can have a healthier life and that effective spaces can contribute to this process. | Enhancing health and safety (assistive and telemedicine technologies). Running automated security routines while absent. Getting things done with less effort. Improving quality of life for ageing people. Saving energy and using natural resources efficiently. |
| Olivia  | She is 18 years old, a “maker” and student, is obese and depressive, and has a robotic pet as she does not have patience for housework. Every six months, she moves to another residence to live the “makers” lifestyle. She believes the world is a great experimental box, and lives to create and connect the online world with offline objects. | Intensifying internet connectivity. Getting things done with less effort. Running automated security routines while absent. Saving energy, money, or time. |
| Victor  | He is 55 years old, a consultant on vertical farms, and is physically active and stressed. He is married, and the couple has a dog. All of his data is in the cloud. He is a “Silver Hopper” who uses the cloud for his work and entertainment. He shares his preferences without worry, and is able to develop smarter relationships and spaces. | Intensifying internet connectivity. Providing entertainment, having more fun. Getting things done with less effort. Saving energy and money or time. Using natural resources efficiently. |
| Beatriz | She is 32 years old, is a “data miner”, and works virtually. She has a wife and a son, a flexible life, and income uncertainty. All her information is in the cloud, and she monitors health using wearables and grows food in a community organic garden. She is a digital native but also always finds time for her son Jonas. Her challenge is to balance the time available between health, work, and family, optimizing as much as she can. | Intensifying internet connectivity. Getting things done with less effort. Enhancing health and safety. Saving energy and money or time. Using natural resources efficiently. Running automated security routines while absent. Providing entertainment, having more fun with family. |
| Michel  | He is 38 years old, and is a virtual actor who is obese and depressive. He spends 90% of his time in the virtual world. He is famous in the virtual world and has difficulty identifying himself with the real world, which seems unlikely to be flexible. He has a few creative stimuli. He spends very little money in his daily life and saves a lot. He perceives the importance of having space at home for relaxing. | Providing peace of mind. Intensifying internet connectivity. Intensifying existing services (e.g., audiovisual entertainment) Getting things done with less effort. |
| Carla   | She is 45 years old, has two children and two jobs (“elderly care giver” and “end-of-life planner”). Worried about her financial sustainability, she presents emotional imbalance, and her DNA indicates a high probability of developing dementia. Her life purpose is to help other people, and she has no time to value herself. She believes that aging people should focus on a healthier life and recovery from their lost years. | Saving energy, money or time. Enhancing health and safety with support of assistive and telemedicine technologies. Providing peace of mind. Intensifying existing services (e.g., audiovisual entertainment) Getting things done with less effort. |

4.3.3. Definition of Selection Criteria for Choosing the Best Smart Home Conception

Table 4 presents the criteria categories and selection criteria adopted for choosing the best smart home conception for the NO.V.A. Project.
Table 4. Criteria categories and selection criteria for choosing the best smart home conception.

| Criteria Category | Selection Criteria | Sources |
|-------------------|--------------------|---------|
|                   | (1)                | (2)    | (3) |
| User desirability | Comfort and entertainment | x | x | x |
|                   | Healthcare         | x      |    |
|                   | Safety and security| x      | x   |
| Sustainable building | Efficiency of home functions | x | x | x |
|                   | Technological innovation | x |    |
| Environmental sustainability | Environmental benefits | x | x | x |

Sources: (1) Wilson et al. [20]; (2) GhaffarianHoseini et al. [25]; (3) Wong e Li [60].

They were defined by the Project Team, taking into account the convergence among the criteria described in previous works on the selection of smart home conceptions [21,25,60], considering two perspectives: (i) user-centricity—criteria under ‘user desirability category’ and (ii) sustainability—criteria under ‘sustainable building’ category. After establishing the selection criteria, during the ideation phase, experts were invited to participate in a survey for assigning weights to these criteria using the AHP method.

4.4. Phase III: Ideation

In this phase, the Project Team used the general morphological analysis (GMA), described in Section 3.3, for creating six alternative smart home conceptions. Afterward, the hybrid AHP-TOPSIS method was employed to rank the alternative conceptions and select the best one.

4.4.1. Creation of Alternative Smart Home Conceptions: Use of the General Morphological Analysis (GMA)

Table 5 summarizes the categories of services and functions that were considered for designing a generic morphological matrix and creating alternative smart homes conceptions.

Table 5. Categories of services and functions of a smart home: designing a generic morphological matrix.

| Category            | Services                                      | Functions                                                                 | Authors                |
|---------------------|-----------------------------------------------|---------------------------------------------------------------------------|------------------------|
| Comfort and         | To provide comfort and smart entertainment     | Lighting, temperature, and heating control; arrange home environment      | [6,20,21,74–76].      |
| entertainment       | options.                                      | according to the future residents’ desire; home appliance control; TV      |                        |
|                     |                                               | program and movies selection, cooking recipe display, meditation sessions,  |                        |
|                     |                                               | and games.                                                                |                        |
| Home automation     | Automate home appliances control.             | Voice-operated appliance control; intelligent appliance monitoring, and   | [77,78].               |
|                     |                                               | control.                                                                   |                        |
| Remote access       | Remote access, monitoring, and control.       | Appliance monitoring and control via mobile devices and computers from    | [79–82].               |
|                     |                                               | distance location; appliance monitoring and control through web browser     |                        |
|                     |                                               | from a remote location; controlling and monitoring home appliances from    |                        |
|                     |                                               | a remote location.                                                         |                        |
Table 5. Cont.

| Category                        | Services                              | Functions                                                                 | Authors |
|---------------------------------|---------------------------------------|---------------------------------------------------------------------------|---------|
| Network and information security | Cyber security.                       | User and device authentication.                                           | [75,83].|
|                                 |                                       | Antivirus and encrypted data.                                              |         |
|                                 |                                       | Cyber security.                                                           |         |
|                                 | Wellness monitoring.                  | Graphical representation of wellness; respiratory and sleeping disorders  | [11,13,17,84].|
|                                 |                                       | assessment; activity tracking, and alarm generation; sleeping stage        |         |
|                                 |                                       | recognition.                                                              |         |
| Healthcare                       | Aging in place.                       | Fall, immobility and reaction incapacity identification; services to     | [8,9,12,85,86].|
|                                 |                                       | provide comfort and safety to the elderly residents, lighting control.    |         |
|                                 | Telemedicine.                         | Supporting elderly and disabled residents; abnormal sleeping disorder,    | [8,11,13,17,84,87].|
|                                 |                                       | unexpected inactivity, uncomfortable home temperature, fridge usage       |         |
|                                 |                                       | disorder; monitoring and analysis of personal health data. Medical        |         |
|                                 |                                       | support from a remote location.                                           |         |
|                                 | Patient support.                      | Services to provide sit-to-stand duration; cooker and night light control| [8,13–15].|
|                                 |                                       | for a patient suffering dementia.                                        |         |
| Efficient use of natural        | Ecological awareness and efficient    | Hydraulic and drainage system; waste management and treatment; water      | [88,89].|
| resources *                     | use of natural resources.             | catchment, treatment, and reuse; bio digesters; vegetable cultivation;    |         |
|                                 |                                       | green roof.                                                               |         |
| Energy resources and management | Energy micro generation and storage.  | Efficiently providing all the energy required by house devices. Managing  | [3,23,39,40,78,88–92].|
|                                 | Energy conservation.                  | energy automatically and intelligently while considering the preferences  |         |
|                                 | Energy efficiency.                    | of residents.                                                             |         |
|                                 | Integration to a smart grid.          | Intelligent integration a smart grid, seeking to minimize the use of     |         |
|                                 |                                       | natural resources and energy costs.                                       |         |
| Surveillance and property       | Monitoring and detection of abnormal  | Monitoring by cameras and detection sensors of abnormal behavioral and    | [61,62,83].|
| security                        | and risky situations.                 | risky situations.                                                         |         |
| Note: (*) Efficient use of      |                                       | Natural resources, except energy resources. Source: Based on Alam et al.  |         |
| resources.                      |                                       | [6]; Marikyan et al. [7]; Kim et al. [15]; De Silva et al. [61,62].        |         |

After considering a literature review on smart home projects and the ideas obtained from the crowdsourcing process, the Project Team and representatives of focal groups (the same formed in the analysis/synthesis phase) built a generic morphological matrix (Figure 4) as the basis for creating the alternative smart home conceptions. The premise for creating these conceptions was to adopt a user-centric and sustainable perspective for all of them by focusing on the future resident as the unit of analysis and the recipient of smart home technology services and functions. As a result of the GMA application, several alternative conceptions were created, but only six were selected for the next stage. Due to limitation of space, only the Conception #6 will be presented in this paper (Figure 5). The cells highlighted in gray correspond to technological solutions that were considered in this conception.

4.4.2. Selection of the Best Smart Home Conception: Use of the Hybrid AHP-TOPSIS Method

The AHP method was used to weight the selection criteria categories and criteria with the support of Super Decisions software. The weights of both (categories and criteria) are shown in Tables 6 and 7, respectively.
Table 6. Weighting criteria categories by the AHP method.

| Criteria Category       | Weight | Consistency Ratio |
|-------------------------|--------|-------------------|
| User desirability       | 0.411  | 0.046             |
| Sustainable building    | 0.261  |                   |
| Environmental sustainability | 0.328  |                   |

Table 7. Weighting selection criteria by the AHP method.

| Criteria Category                | Criteria                        | Weight | Consistency Ratio |
|----------------------------------|---------------------------------|--------|-------------------|
| User desirability                | Comfort and entertainment        | 0.333  | 0.000             |
|                                  | Healthcare                       | 0.333  |                   |
|                                  | Safety and security              | 0.333  |                   |
| Sustainable building             | Efficiency of home functions     | 0.500  | 0.000             |
|                                  | Technological benefits           | 0.500  |                   |
| Environmental sustainability     | Environmental benefits           | 1.000  | 0.000             |

The final weights of criteria shown in Table 8 were obtained by multiplying the weight values from Tables 6 and 7.

Table 8. Final weighting of selection subcriteria from the AHP method.

| Criteria Category                | Criteria                        | Final Weights |
|----------------------------------|---------------------------------|---------------|
| User desirability                | Comfort and entertainment        | 0.137         |
|                                  | Healthcare                       | 0.137         |
|                                  | Safety and security              | 0.137         |
| Sustainable building             | Efficiency of home functions     | 0.131         |
|                                  | Technological benefits           | 0.131         |
| Environmental sustainability     | Environmental benefits           | 0.328         |

With the support of GMA, six alternative smart home conceptions were created, and the best one was chosen from the convergence of the multicriteria ranking and the target audiences’ acceptance, represented by six personas.

For ranking the smart home conceptions, a scale ranges from 1 to 5 was defined as follows: (i) score 1—the conception does not meet the criteria; (ii) score 3—the conception meets moderately the criteria; (iii) score 5—the conception fully meets the criteria. Scores 2 and 4 refer to the intermediate values of the scale (Table 9).

Table 9. Attribute map for ranking smart home conceptions.

| Smart Home Conceptions | Criteria | Criteria | Criteria | Criteria | Criteria |
|------------------------|----------|----------|----------|----------|----------|
|                        | Comfort and Entertainment | Healthcare | Safety and Security | Efficiency of Home Functions | Technological Benefits | Environmental Benefits |
| Conception #1          | 5        | 2        | 4        | 4        | 4        | 2         |
| Conception #2          | 2        | 1        | 1        | 2        | 2        | 1         |
| Conception #3          | 3        | 2        | 1        | 3        | 3        | 1         |
| Conception #4          | 4        | 2        | 1        | 3        | 3        | 1         |
| Conception #5          | 5        | 4        | 3        | 2        | 3        | 2         |
| Conception #6          | 5        | 3        | 4        | 4        | 4        | 4         |
Through the Euclidean Distance between the smart home conceptions, it was possible to calculate
the Positive Ideal and Negative Ideal Solutions (PIS and NIS), and the Closeness Coefficient (CCi) for
each conception. The ranking of the six alternative smart home conceptions is shown in Table 10.

Table 10. Ranking of alternative smart home conceptions by the AHP/TOPSIS method.

| Smart Home Conceptions | Closeness Coefficient (CCi) | Ranking |
|------------------------|----------------------------|---------|
| Conception #6          | 0.87                       | 1       |
| Conception #1          | 0.57                       | 2       |
| Conception #5          | 0.54                       | 3       |
| Conception #4          | 0.28                       | 4       |
| Conception #3          | 0.24                       | 5       |
| Conception #2          | 0.00                       | 6       |

As recommended in Section 3.3.2, the final decision depended on the evaluation of the target
audiences’ acceptance regarding each alternative conception. Accordingly, Table 11 shows the results
of this final analysis.

Table 11. Selection of the best smart home conception: convergence of the multicriteria ranking and
the target audience (s) acceptance.

| Smart Home Conception | Conception #1 | Conception #2 | Conception #3 | Conception #4 | Conception #5 | Conception #6 |
|------------------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Closeness Coefficient  | 0.57          | 0.00          | 0.24          | 0.28          | 0.54          | 0.87          |
| Ranking                | 2             | 6             | 5             | 4             | 3             | 1             |
| Personas’ needs and aspirations | Maria Vitor Beatriz Carla | Maria Michel Carla Olivia | Maria Michel Beatriz Carla | Maria Michel Beatriz Carla | Maria Vitor Michel Beatriz Carla |

As can be observed in Table 11, the Conception #6 was chosen as the best alternative for building the
NO.VA. Smart Home. This conception was based on the choice of SHTs addressed to both sustainability
concerns and the future residents’ needs and aspirations (i.e., comfort, entertainment, automation and
safety, and also assistive and telemedicine technologies for aging and disabled residents).
| Categories of services                          | SHT1                  | SHT2                  | SHT3                  | SHT4                  | SHT5                  | SHT6                  | SHT7                  | SHT8                  | SHT9                  | SHT10                 | SHT11                 | SHT12                 | SHT13                 |
|------------------------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| Comfort and entertainment                      | HVAC system           | Digital addressable   | Lighting system       | Internal layout        | Building facade system | Honoo Area Network    | Internal and external | Non-invasive          | Smart furniture        | Shading system         | Intelligent           | virtual assistant     | Smart furniture        |
| Home automation                                | Addressable fire      | Telecomm and data     | Integrated building   | Security monitoring    | Internal layout        | Lighting system       | Building facade system | Vertical transport    | Home Area Network     | Internal and external | Non-invasive          | positioning detection | system                | system                |
| Remote access                                  | Telecom and data      | Internet of things    | Digital addressable   | Integrated building    | Building facade system | Intelligent           | Smart home technology  | Energy harvesting     | Internal and external | Efficiency            | energy harvesting     | devices                | system                | system                |
| Network and information security               | Security monitoring   | Information system    | Internet of things    | Internet of things     | Smart furniture         | Wearable health       | Energy harvesting     | Internal and external | system                | system                | system                | system                | system                |
| Healthcare                                      | Integrated building   | Internal layout       | Vertical transport    | Smart furniture         | Energy harvesting      | Energy harvesting     | Energy harvesting     | Solar energy harvesting | system                | system                | system                | system                | system                |
| Efficient use of natural resources             | Hydraulic and         | Water treatment       | Rainwater harvesting  | Meteorological station | Biogas plant           | Green roof            | Vegetable cultivation | Energy harvesting     | Energy harvesting     | Energy harvesting     | Energy harvesting     | devices                | system                | system                |
| Energy resources and management                | Energy management     | Internal and external | Meteorological station| PV system              | OPV - organic PV system| Geothermal energy      | Solar energy harvesting| system                | system                | HVAC system            | Lighting system         | Battery system         | Energy harvesting     | devices                |
| Surveillance and property security             | Fire protection       | Addressable fire      | Security system       | Smart door lock        | Internet of things     | Smart home technology  | Energy harvesting     | Energy harvesting     | Energy harvesting     | Energy harvesting     | Energy harvesting     | devices                | system                | system                |

**Figure 4.** The generic morphological matrix for creating alternative smart home conceptions.
| Categories of services | SHT1                          | SHT2                          | SHT3                          | SHT4                          | SHT5                          | SHT6                          | SHT7                          | SHT8                          | SHT9                          | SHT10                         | SHT11                         | SHT12                         | SHT13                         |
|------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| Comfort and entertainment | HVAC system                  | Digital addressable lighting control system | Lighting system              | Internal layout system         | Building facade system        | Home Area Network (HAN)       | Internal and external mgmt system | Non-invasive positioning detection system | Smart furniture               | Shading system                | Intelligent virtual assistant | Smart furniture               | Smart furniture               |
| Home automation        | Addressable fire detection and alarm system | Telecom and data system        | Integrated building system    | Security monitoring and access control system | Internal layout system         | Lighting system              | Building facade system        | Vertical transport system      | Home Area Network (HAN)       | Internal and external mgmt system | Non-invasive positioning detection system | Smart furniture               |
| Remote access          | Telecom and data system      | Internet of things (IoT)      | Digital addressable lighting control system | Integrated building mgmt system | Building facade system        | Intelligent virtual assistant | Smart furniture               | Smart furniture               | Smart furniture               | Smart furniture               | Smart furniture               | Smart furniture               |
| Network and information security | Security monitoring and access control system | Information system and communication network | Internet of things (IoT) | Internet of things (IoT) | Smart furniture | Wearable health tracking | Energy harvesting devices | Internal and external mgmt system | Smart furniture | Smart furniture | Smart furniture | Smart furniture |
| Healthcare              | Integrated building mgmt system | Internal layout system        | Vertical transport system     | Smart furniture                | Wearable health tracking      | Energy harvesting devices     | Internal and external mgmt system | Smart furniture | Smart furniture | Smart furniture | Smart furniture |
| Efficient use of natural resources | Hydraulic and drainage system | Water treatment plant         | Rainwater harvesting          | Meteorological station         | Biodigester                   | Green roof                   | Vegetable cultivation             | Smart furniture | Smart furniture | Smart furniture | Smart furniture |
| Energy resources and management | Energy management system (general) | Internal and external mgmt systems | Meteorological station | PVT - photovoltaic and thermal system | PV system                   | OPV - organic PV system       | Geothermal energy system       | Solar energy heating water system | Horizontal wind turbine | HVAC system                  | Lighting system               | Battery system                | Energy harvesting devices |
| Surveillance and property security | Fire protection system | Addressable fire detection and alarm system | Security system              | Smart door lock                | Internet of things (IoT)      | Security system               | Smart door lock                | Internet of things (IoT)      | Smart door lock                | Internet of things (IoT)      | Smart door lock                | Internet of things (IoT)      | Smart door lock                |

**Figure 5.** The morphological representation of Conception #6.
4.5. Phase IV: Prototyping

Prototyping was carried out according to: (i) the NO.V.A. Project Team and institutional partners’ perspective; and (ii) the stakeholders’ and future residents’ perspectives.

From the internal perspective, the architectural pre-design and the basic project were developed by a local renowned architecture firm, and a virtual tour video was created and provided for target audiences.

The NO.V.A. Smart Home is located within a wooden park and the circular facade intertwined with existing trees to preserve its landscape (Figure 6). It is in a neighborhood with several types of buildings, including a federal university and a shopping center nearby. The park where the smart home is located is close to the waterfront in Niteroi City, and a few meters from the ferryboat service. These features contribute to the exposition of the Project.

![Figure 6. The NO.V.A. Smart Home.](image1)

A singular characteristic of the NO.V.A. Smart home is a co-working space near the main house where the residents can share with visitors (Figure 7).

![Figure 7. Co-working space, house systems, and green roofs.](image2)

Due to concerns involving environmental sustainability, the house will be self-sufficient in energy and will function as a microgrid, producing about 105% of its energy demand, thanks to the solar
energy generated by solar panels installed on the roof. In addition, wind turbines will be installed to capture wind energy to turn it into electrical energy (Figure 7).

The surplus energy can be stored in high capacity batteries or transferred to the local distribution network, increasing the production and consumption of clean energy. In addition, the project was designed so that it is not necessary to use electricity during the day.

Its construction will reduce waste volumes by up to 85% and carbon emissions by 80% compared to a conventional house of the same size. It will be the first construction in South America to compete for the Living Building Challenge (LBC) certification—an international seal with a rigorous performance standard that certifies buildings of all scales that operate cleanly and responsibly with the environment.

From the resident’s perspective, once constructed, the NO.V.A. smart home will function as a “living lab”, where ordinary people will be able to cooperate with the Project, living on site and testing the innovative solutions daily presented. Technologies and their impacts on the daily life and consumption habits of residents will be monitored, with the aim of improving the sustainable innovative solutions offered by the NO.V.A. Project.

5. Discussion

As stated in the introductory session, an important debate has been raised in recent years regarding two design visions for smart home projects. First, the view of a desired smart home, as a home that enhances people’s experiences of comfort, entertainment, safety and security through pervasive technologies [20–22]. Second, the progressive search for designing sustainable smart homes [23–25,27]. In most smart home research, these visions have been addressed separately and potentially weaken each other.

In this paper, we approached this dilemma by bringing user-centric and sustainable perspectives together accordingly to the criteria defined for selecting alternative smart home conceptions, as follows: (i) user-centricity—‘comfort and entertainment’, ‘healthcare’, ‘safety and security’ criteria, including the acceptance of pervasive technologies; and (ii) sustainability—‘efficiency of home functions’, ‘building technological innovations focusing on sustainability’, and ‘environmental benefits’). During the ideation phase of the NO.V.A. Project, the criteria weighting took into account the balance between both perspectives.

The differentials of Smart Home Conception #6 shown in Figure 4 are directly related to the fact that it focuses on future-residents’ aspirations, thinking about the usability of the smart home as well as the acceptance of assistive technologies by the elderly and disabled residents. At the same time, this conception was strongly concerned with sustainable building and the environmental benefits of adopting the technological innovations to be embedded in its construction. They include the generation and storage of clean energies, as well as the optimization of resources through smart systems, adoption of cross ventilation and skylights, among others.

Foreseeing the potential benefits from both perspectives was decisive for this smart home conception to be in the first position when compared with the other five conceptions created during the ideation phase of the NO.V.A. Project.

A systematic literature review conducted by authors indicated that the DT approach has rarely been exploited in smart home projects [8,34,35]. Although these previous works adopted DT methods and tools, none of them took into account the conception of a smart home that considers both user-centricity and sustainability perspectives. In that regard, the NO.V.A. Project offered a rich multistakeholder environment to demonstrate the applicability of a conceptual model combining the DT approach with crowdsourcing, morphological analysis, and multicriteria decision-making methods (MCDM), aiming to create and select a smart home conception from a more empathetic perspective, i.e., putting people at the center of the smart home project and taking into account the adoption and acceptance of sustainable technological innovations.

It was considered that all people directly involved in the NO.V.A. Project—the sponsors and other stakeholders’ representatives, the Project Team, the research partners, and also the architecture firm
that participated in the prototyping phase—were able to incorporate the necessary attributes to meet the needs and aspirations of future residents and materialize the sustainability vision preconized by Enel Distribuição Rio for this Project.

6. Conclusions

In this paper, an attempt was made to demonstrate in practice the benefits of adopting a model for creating and selecting user-centric and sustainable smart home conceptions based on the Design Thinking approach combined with advanced innovation management tools and a hybrid multicriteria decision-making method (AHP-TOPSIS). The application of this model will allow decision-makers and experts responsible for coordinating smart home projects to place their future residents at the center of their development, generating and selecting alternatives that come to meet the desires, expectations, and needs of these people that can be turned into reality.

The innovative aspects of the model based on Design Thinking are highlighted, as follows:

- Creation of a digital collaboration platform (crowdsourcing) in the immersion phase
- Identification of archetypes of typical future residents (personas) which represent the motivations, desires, expectations, and needs, revealing themselves to be significant characteristics of a broader group during the analysis/synthesis phase;
- Definition of a guiding criteria for ranking alternatives based on innovative technological solutions and selecting the best smart home conceptions in the user-centric and sustainable perspectives;
- In the ideation phase, adoption of the general morphological analysis (GMA) to create consistent conceptions of smart homes based on innovative technological solutions, while considering user-centricity and sustainability;
- Use of a hybrid multicriteria decision-making method (AHP-TOPSIS) for selecting the best smart home conception that will bridge the gap between the functions offered by smart services and future residents’ needs and expectations.

Finally, it should be noted that the results presented here contributed to the choice of innovative technological solutions to be embedded in a smart home project in Brazil, developed by a private player in energy distribution in this country in cooperation with two local universities (PUC-Rio and FGV).

As future works, we suggest: (i) use of new innovation management tools and technological foresight techniques, e.g., Delphi, technology roadmapping; future scenarios; (ii) adoption of new combinations of multicriteria methods in the DT ideation phase, particularly for ranking the alternative smart home conceptions; and (iii) development of new taxonomies and disruptive technologies for smart homes, while considering specificities of developing countries and emerging economies.

Author Contributions: M.F.A. and R.C. conceived and designed the research; F.M. performed the literature review and documentary analysis; M.F.A. wrote the Section 2; R.C. wrote the Section 3; F.M. and A.O. wrote the empirical validation of the conceptual model in a real organizational context (Section 4); and F.M., M.F.A., and R.C. jointly wrote the introduction (Section 1), discussion of results (Section 5), and conclusions (Section 6). All authors commented on all the sections and reviewed the final manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Enel Distribuição Rio de Janeiro (Enel Group) and two Brazilian Funding Agencies: Coordination for the Improvement of Higher Education Personnel (acronym in Portuguese; Capes) and the National Council for Scientific and Technological Development (acronym in Portuguese; CNPq).

Acknowledgments: The authors wish to thank the participants of the NO.VA. Project carried out by Enel Distribuição Rio de Janeiro for constructive discussions and judgments during the implementation of the conceptual model (phases I to IV). The authors thank Enel Distribuição Rio de Janeiro and two Brazilian Funding Agencies (CNPq and Capes) for the financial support provided. Special thanks go to the anonymous reviewers for their careful reading of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.
References

1. Yang, S.; Yang, N.; Hu, J.; Wang, G. Design and Implementation of Mobile Intelligent Terminal Network Communication in Smart Home. In Proceedings of the 2016 International Conference on Energy, Power and Electrical Engineering, Shenzhen, China, 30–31 October 2016.

2. Xu, K.; Wang, X.; Wei, W.; Song, H.; Mao, B. Toward software defined smart home. IEEE Commun. Mag. 2016, 54, 116–122. [CrossRef]

3. Zhou, B.; Li, W.; Chan, K.W.; Cao, Y.; Kuang, Y.; Liu, X.; Wang, X. Smart home energy management systems: Concept configurations and scheduling strategies. Renew. Sustain. Energy Rev. 2016, 61, 30–40. [CrossRef]

4. Jacobsson, A.; Boldt, M.; Carlsson, B. A risk analysis of a smart home automation system. Future Gener. Comput. Syst. 2016, 56, 719–733. [CrossRef]

5. Toschi, G.M.; Campos, L.B.; Cugnasca, C.E. Home automation networks: A survey. Comput. Stand. Interfaces 2017, 50, 42–54. [CrossRef]

6. Alam, M.R.; Reaz, M.B.I.; Ali, M.A.M. A review of smart homes—Past, present, and future. IEEE Trans. Syst. Man Cybern. Part C Appl. Rev. 2012, 42, 1190–1203. [CrossRef]

7. Marikyan, D.; Papagiannidis, S.; Alamanos, E. A systematic review of the smart home literature: A user perspective. Technol. Forecast. Soc. Chang. 2019, 138, 139–154. [CrossRef]

8. Dalton, C. Including smart architecture in environments for people with dementia. In Handbook of Smart Homes, Health Care and Well-Being; Springer: Cham, Switzerland, 2016; pp. 335–347.

9. Amiribesheli, M.; Benmansour, A.; Buchachia, A. A review of smart homes in healthcare. J. Ambient Intell. Humaniz. Comput. 2015, 6, 485–517. [CrossRef]

10. Atoyeb, A.O.; Stewart, A.; Sampson, J. Use of information technology for falls detection and prevention in the elderly. Ageing Int. 2014, 40, 277–299. [CrossRef]

11. Röcker, C.; Zieflie, M. E-Health, Assistive Technologies and Applications for Assisted Living: Challenges and Solutions. In Book News; Medical Information Science Reference: Hershey, PA, USA, 2011.

12. Blaschke, C.M.; Freddolino, P.P.; Mulllen, E.E. Ageing and technology: A review of the research literature. Br. J. Soc. Work 2009, 39, 641–656. [CrossRef]

13. Demiris, G.; Hensel, B.K. Technologies for an ageing society: A systematic review of ‘smart home’ applications. Yearb. Med. Inform. 2008, 3, 33–40.

14. Arcelus, I.; Herr, C.L.; Goubran, R.A.; Knoefel, F.; Sveistrup, H.; Bilodeau, M. Determination of sit-to-stand transfer duration using bed and floor pressure sequences. IEEE Trans. Biomed. Eng. 2009, 56, 2485–2492. [CrossRef] [PubMed]

15. Adlam, R.; Faulker, R.; Orpwood, K.; Jones, J.; Macijauskiene, H.; Budraitiene, A. The installation and support of internationally distributed equipment for people with dementia. IEEE Trans. Inform. Technol. Biomed. 2004, 8, 2004. [CrossRef] [PubMed]

16. Kim, M.J.; Cho, M.E.; Jun, H.J. Developing design solutions for smart homes through user-centered scenarios. Front. Psychol. 2020, 11, 335. [CrossRef] [PubMed]

17. Chan, M.; Esteve, D.; Escriva, C.; Campo, E. A review of smart homes—Present state and future challenges. Comput. Methods Progr. Biomed. 2008, 91, 55–81. [CrossRef] [PubMed]

18. Ehrenhard, M.; Kijl, B.; Nieuwenhuis, L. Market adoption barriers of multistakeholder technology smart homes for the aging population. Technol. Forecast. Soc. Chang. 2014, 89, 306–315. [CrossRef]

19. Bregman, D.; Korman, A. A universal implementation model for the smart home. Int. J. Smart Home 2009, 3, 15–30.

20. Wilson, C.; Hargreaves, T.; Hauxwell-Baldwin, R. Benefits and risks of smart home technologies. Energy Policy 2017, 103, 72–83. [CrossRef]

21. Wilson, C.; Hargreaves, T.; Hauxwell-Baldwin, R. Smart homes and their users: A systematic analysis and key challenges. Pers. Ubiquitous Comput. 2015, 19, 463–476. [CrossRef]

22. Hargreaves, T.; Wilson, C.; Hauxwell-Baldwin, R. Learning to live in a smart home. Build. Res. Inf. 2018, 46, 127–139. [CrossRef]
23. Herrero, S.T.; Nicholls, L.; Strengers, Y. Smart home technologies in everyday life: Do they address key energy challenges in households? *Curr. Opin. Environ. Sustain.* 2018, 31, 65–70. [CrossRef]

24. Jensen, R.H.; Strengers, Y.; Kjeldskov, J.; Skov, M.B. Designing the desirable smart home: A study of household experiences and energy consumption impacts. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI ’18), Montreal, QC, Canada, 21–26 April 2018.

25. Ghaffarianhoseini, A.; Dahan, N.D.; Berardi, U.; Makaremi, N. The essence of future smart houses: From embedding ICT to adapting to sustainability principles. *Renew. Sustain. Energy Rev.* 2013, 24, 593–607. [CrossRef]

26. Rodden, T.; Benford, S. The evolution of buildings and implications for the design of ubiquitous domestic environments. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Ft. Lauderdale, FL, USA, 5–10 April 2003.

27. Brown, T. Design Thinking. *Harv. Bus. Rev.* 2008, 86, 84–92.

28. Cooper, R.; Junginger, S.; Lockwood, T. Design thinking and design management: A research and practice perspective. *Des. Manag. Rev.* 2009, 20, 46–55. [CrossRef]

29. Plattner, H.; Meinel, C.; Leifer, L. *Design Thinking*; Springer: Berlin, Germany, 2011.

30. Brenner, W.; Uebernickel, F.; Abrell, T. Design thinking as mindset, process, and toolbox. In *Design Thinking for Innovation: Research and Practice*; Brenner, W., Uebernickel, F., Eds.; Springer: Cham, Switzerland, 2016; pp. 3–24.

31. Micheli, P.; Wilner, S.J.S.; Bhatti, S.H.; Mura, M.; Beverland, M. Doing design thinking: Conceptual review, synthesis, and research agenda. *J. Prod. Innov. Manag.* 2019, 36, 124–148. [CrossRef]

32. Wang, W.; Liu, Y.; Wei, T.; Zhang, Y. Product service model constructing method for intelligent home based on positive creative design thinking. *Int. J. Intel. Syst. Appl. Eng.* 2020, 19, 141–154. [CrossRef]

33. Karagianni, A.; Geropanta, V. Smart homes: Methodology of IoT integration in the architectural and interior design process—A case study in the historical center of Athens. In Proceedings of the International Conference on Intelligent Computing & Optimization, Koh Samui, Thailand, 3–4 October 2019; Vasant, P., Zelinka, I., Weber, G.W., Eds.; Springer: Berlin/Heidelberg, Germany; pp. 222–230. [CrossRef]

34. Tasçıkaraoglu, A.; Boynüneğri, A.R.; Uzunoglu, M. A demand side management strategy based on forecasting of residential renewable sources: A smart home system in Turkey. *Energy Build.* 2014, 80, 309–320. [CrossRef]

35. Jakobi, T.; Ogonowski, C.; Castelli, N.; Stevens, G.; Wulf, V. The catch(es) with smart home: Experiences of a living lab field study. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, Denver, CO, USA, 6–11 May 2017; pp. 1620–1633. [CrossRef]

36. Agelab, M. Home Services and Logistics. 2017. Available online: http://agelab.mit.edu/research (accessed on 27 October 2020).

37. Darby, S.J.; Liddell, C.; Hills, D.; Drabble, D. *Smart Metering Early Learning Project: Synthesis Report*; Department of Energy and Climate Change: London, UK, 2015. Available online: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/407568/8_Synthesis_FINAL_25feb15.pdf (accessed on 27 October 2020).

38. Darby, S.J. Smart technology in the home: For more clarity. *Build. Res. Inf.* 2018, 46, 140–147. [CrossRef]

39. Louis, J.-N.; Calo, A.; Leiviskä, K.; Pongracz, E. Environmental impacts and benefits of smart home automation: Life cycle assessment of home energy management system. *IFAC Pap. OnLine* 2015, 48, 880–885. [CrossRef]

40. Gray, C.; Ayre, R.R.; Hinton, K.; Campbell, L. ‘Smart’ is not free: Energy consumption of consumer home automation systems. *IEEE Trans. Consum. Electron.* 2020, 66, 87–95. [CrossRef]

41. Peine, A. Understanding the dynamics of technological configurations: A conceptual framework and the case of smart homes. *Technol. Forecast. Soc. Chang.* 2009, 76, 396–409. [CrossRef]

42. Oliveira, A.; Calili, R.; Almeida, M.F.; Sousa, M. A systemic and contextual framework to define a country’s 2030 agenda from a foresight perspective. *Sustainability* 2019, 11, 6360. [CrossRef]

43. Malone, T.W.; Laubacher, R.; Dellarocas, C.N. *Harnessing Crowds: Mapping the Genome of Collective Intelligence*. MIT Sloan Research Paper No. 4732-09. 2009. Available online: https://ssrn.com/abstract=1381502 or http://dx.doi.org/10.2139/ssrn.1381502 (accessed on 27 October 2020).
44. Schenk, E.; Guittard, C. Towards a characterization of crowdsourcing practices. *J. Innov. Econ. Manag.* 2011, 1, 206–223. [CrossRef]
45. Kim, J.; Kim, K.-Y.; Kwon, O. Actor network theory-based modeling for crowdsourced design team formation. *J. Integr. Des. Process. Sci.* 2016, 19, 37–61. [CrossRef]
46. Mount, M.; Round, H.; Pitsis, T.S. Design Thinking inspired crowdsourcing: Toward a generative model of complex problem solving. *Calif. Manag. Rev.* 2020, 62, 103–120. [CrossRef]
47. Afuah, A.; Tucci, C. Crowdsourcing as a solution to distant search. *Acad. Manag. Rev.* 2012, 37, 355–375. [CrossRef]
48. Howe, J. The rise of crowdsourcing. *Wired Mag.* 2006, 14, 1–5. Available online: http://www.wired.com/wired/archive/14.06/crowds.html (accessed on 27 October 2020).
49. Brabham, D.C. Crowdsourcing as a model for problem solving: An introduction and cases. *Converg. Int. J. Res. New Media Technol.* 2008, 14, 75–90. [CrossRef]
50. Zwicky, F. *Discovery, Invention, Research—Through the Morphological Approach*; Macmillan Publishers: New York, NY, USA, 1969.
51. Ritchey, T. *Modelling Complex Socio-Technical Systems Using Morphological Analysis*; 2003; Available online: http://www.swemorph.com/pdf/it-webart.pdf (accessed on 27 October 2020).
52. Ritchey, T. Outline for a morphology of modeling methods: Contribution to a general theory of modelling. *Acta Morphol. Gen.* 2012. Available online: http://www.amg.swemorph.com/pdf/amg-1-1-2012.pdf (accessed on 27 October 2020).
53. Ritchey, T. *Wicked Problems–Social Messes: Decision Support Modelling with Morphological Analysis*; Springer: Berlin/Heidelberg, Germany, 2011.
54. Saaty, T.L. *The Analytic Hierarchy Process*; McGraw-Hill: New York, NY, USA, 1980.
55. Wong, J.K.W.; Li, H. Application of the analytic hierarchy process (AHP) in multicriteria analysis of the selection of intelligent building systems. *Build. Environ.* 2008, 43, 108–125. [CrossRef]
56. Álvarez, A.; Ritchey, T. Applications of general morphological analysis: From engineering design to policy analysis. *Acta Morphol. Gen.* 2015, 4, 1–40. Available online: http://www.amg.swemorph.com/pdf/amg-4-1-2015.pdf (accessed on 27 October 2020).
57. De Silva, L.C.; Darussalam, B. State of the art of smart homes. *Int. J. Smart Sens. Intell. Syst.* 2008, 1, 220–245. [CrossRef]
58. De Silva, L.C.; Morikawa, C.; Petra, I.M. State of the art of smart homes. *Eng. Appl. Artif. Intell.* 2012, 25, 1313–1321. [CrossRef]
59. Badica, C.; Brezovan, M.; Badica, A. An overview of smart home environments: Architectures, technologies and applications. In Proceedings of the Balkan Conference in Informatics (BCI’13), Thessaloniki, Greece, 19–21 September 2013.
60. Fern, E. *Advanced Focus Group Research*; Sage Publications: Thousand Oaks, CA, USA, 2001.
68. Cooper, A. *The Inmates Are Running the Asylum: Why High Tech Products Drive Us Crazy and How to Restore the Sanity*; Sams Publishing: Carmel, IN, USA, 1999.

69. Cooper, A.; Reimann, R.; Cronin, D. *About Face 3: The Essentials of Interaction Design*; Wiley Publishing, Inc.: Indianapolis, IN, USA, 2007.

70. Grudin, J.; Pruitt, J. Personas, participatory design, and product development: An infrastructure for engagement. In *Proceedings of the Participatory Design Conference 2002*, Malmo, Sweden, 23–25 June 2002.

71. Welsh, M.A.; Dehler, G.E. Combining critical reflection and design thinking to develop integrative learners. *J. Manag. Educ.* 2012, 37, 771–802. [CrossRef]

72. Creative Decision Foundation. *Super Decisions V.3.2 Manual*; 2019; Available online: https://www.superdecisions.com/manuals/ (accessed on 27 October 2020).

73. Mu, E.; Pereyra-Rojas, M. *Practical Decision Making Using Super Decisions v3: An Introduction to the Analytic Hierarchy Process*; Series: Springer Briefs in Operations Research; Springer: Basel, Switzerland, 2018.

74. Triboan, D.J.; Chen, L.; Chen, F.; Wang, Z. Towards a service-oriented architecture for a mobile assistive system with real-time environmental sensing. *Tsinghua Sci. Technol.* 2016, 21, 581–597. [CrossRef]

75. Arnuvivek, J.; Srinath, S.; Balamurugan, M.S. Framework development in home automation to provide control and security for home automated devices. *Indian J. Sci. Technol.* 2015, 8. [CrossRef]

76. Sun, H.; De Florio, V.; Gui, N.; Blondia, C. The missing ones: Key ingredients towards effective ambient assisted living systems. *J. Ambient Intell. Smart Environ.* 2010, 2, 109–120. [CrossRef]

77. Swaminathan, R.; Nischt, M.; Kuhnel, C. Localization based object recognition for smart home environments. In *Proceedings of the IEEE International Conference Multimedia Expo*, Hannover, Germany, 23–26 June 2008.

78. Chen, C.-Y.; Tsoul, Y.-P.; Liao, S.-C.; Lin, C.-T. Implementing the design of smart home and achieving energy conservation. In *Proceedings of the 7th IEEE International Conference of Industrial Informatics*, Cardiff, UK, 23–26 June 2009.

79. Perumal, T.; Ramli, A.R.; Leong, C.Y. Design and implementation of SOAP-based residential management for smart home systems. *IEEE Trans. Consum. Electron.* 2008, 54, 453–459. [CrossRef]

80. Wang, Z.; Wei, S.; Shi, L.; Liu, Z. The analysis and implementation of smart home control system. In *Proceedings of the International Conference on Information Management and Engineering*, Kuala Lumpur, Malaysia, 3–5 April 2009.

81. Yongping, J.; Zehao, F.; Du, X. Design and application of wireless sensor network web server based on S3C2410 and zigbee protocol. In *Proceedings of the International Conference on Networks on Security, Wireless Communications and Trusted Computing*, Wuhan, China, 25–26 April 2009.

82. Ahvar, E.; Daneshgar-Moghaddam, N.; Ortiz, A.; Lee, G.; Crespi, N. On analyzing user location discovery methods in smart homes: A taxonomy and survey. *J. Netw. Comput. Appl.* 2016, 76, 75–86. [CrossRef]

83. Chitnis, S.; Deshpande, N.; Shaligram, A. An investigative study for smart home security: Issues, challenges and countermeasures. *Wirel. Sens. Netw.* 2016, 8, 61–68. [CrossRef]

84. Raad, M.W.; Yang, L.T. A ubiquitous smart home for elderly. In *Proceedings of the 4th IET International Conference on Advances in Medical, Signal and Information Processing (MEDSIP 2008)*, Santa Margherita Ligure, Italy, 14–16 July 2008.

85. Farella, E.; Falavigna, M.; Ricco, B. Aware and smart environments: The Casattenta Project. In *Proceedings of the 3rd International Workshop on Advanced in Sensors and Interfaces*, Bari, Italy, 25–26 June 2009.

86. Vainio, A.-M.; Valtonen, M.; Vanhala, J. Proactive fuzzy control and adaptation methods for smart homes. *IEEE Intell. Syst.* 2008, 23, 42–49. [CrossRef]

87. Cho, M.E.; Oh, Y.J.; Kim, M.J. Development of a health smart home model for the elderly. *J. Korean Hous. Assoc.* 2018, 29, 81–90. [CrossRef]

88. Lobaccaro, G.; Carlucci, S.; Lofstrom, E. A review of systems and technologies for smart homes and smart grids. *Energies* 2016, 9, 348. [CrossRef]

89. Vastardis, N.; Kampouridis, M.; Yang, K. A user behaviour-driven smart-home gateway for energy management. *J. Ambient Intell. Smart Environ.* 2016, 8, 583–602. [CrossRef]

90. Strengers, Y.; Nicholls, L. Convenience and energy consumption in the smart home of the future: Industry visions from Australia and beyond. *Energy Res. Soc. Sci.* 2017, 32, 86–93. [CrossRef]
91. Borsekova, K.; Kourtit, K.; Nijkamp, P. Smart development, spatial sustainability and environmental quality. *Habitat Int.* **2017**, *68*. [CrossRef]

92. Hosseini, S.S.; Agbossou, K.; Kelouwani, S.; Cardenas, A. Non-intrusive load monitoring through home energy management systems a comprehensive review. *Renew. Sustain. Energy Rev.* **2017**, *79*, 1266–1274. [CrossRef]

**Publisher’s Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).