PROCESSES

13.0 DESIGN PROCESS

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ABSTRACT
System Design is both a scientific and a creative process. In the last few years several techniques have been proposed to address the problem of developing a new conceptual design of a robot in a systematic way. From this literature survey, it can be seen how the design process of robots mainly consists of four phases: (1) need identification, i.e. system functional specifications, (2) identification of subsystem technical specifications, (3) evaluation of the technical specifications and selection of the most suitable to meet functional requirements, (4) evaluation of the whole system both from the user satisfaction and ethical point of view. The present reviews show different approaches for the development of system design and evaluation of the process, both form technical and ethical point of view.

13.1 Opening

Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic science and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation. The engineering design process include a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics and social impact [ABET Definition of Design].

In another approach, adapted from Gero (Gero, 1990), an analytical model for a design can be given as a function in the following way:

D = f (F, B, S, K, C)

where

D = Design of the product

F = Functions intended to be performed by the product

B = Behavior of the structural elements that provide the intended functions

S = Structural attributes

K = Knowledge used in the design

C = Context of the product

From these definitions it is evident that design is both a scientific and a creative process.

Albert Einstein's assertion "imagination is more important than knowledge, for knowledge is finite whereas imagination is infinite" reaches its full embodiment in design process (Haik et al., 2015).

The design process is basically and exercise in creativity. The complete process may be outlined by design flow diagrams with feedback loops. Figure 1 shows some aspects of such a diagram.

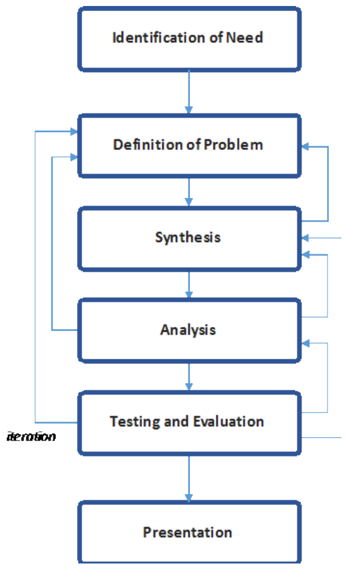

Figure 1. Design Process Diagram

Most engineering designs involve safety, ecological and societal considerations. It is a challenge to engineer to recognize all of these in a proper proportion. Fundamental actions proposed for the design process are establishing a need as a design problem to be solved, understanding the problem, generating and evaluating possible solutions and deciding on the best solution (Ugural, 2016).

In order to better focus this review to REELER field, the review was carried out between documents contained in the title, keywords or abstract the words "design process" AND robots.

The objective of REELER is to “close the proximity gap in human-robot interaction design and development to ensure a more responsible, ethical uptake of new robots by affecting the process of robot design”. Therefore, a comprehensive knowledge of the design process is needed to improve this aspect.

13.2 Methodology

A preliminary literature search has been performed for the concept *design process* to determine how this concept has been studied thus far. Being the search for the term *design process* too generic, it was necessary to add the *robot* keyword for all subsequent bibliographic searches, in order to better focus this review to REELER field

The search was then carried out between documents contained in the title, keywords or abstract the words *design process* AND *robots.*

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The SCOPUS database was used for search over single word (Design Proccess AND Robot) and combined words (Design Process + Robot + learning / collaborative learning / ethics / human/ user* / ethnography / anthropology). Most of the articles were excluded from first screening on title and abstract, whereas final significant articles were selected after full reading.

13.3 Discussion

Design and construction of robots is time-consuming and often leads to an expensive series of functional prototypes converging on an acceptable design. In general, budgets (and time considerations) require that the first design be sufficient for use and that only minor modifications are needed. Essentially, due to costs, the design of robots is an open loop process where the best guess at minimizing the error guides the construction. This subjective appraisal is usually incorporated into design processes by creating functional mock-ups for evaluation by large number of potential users.

This type of design feedback is expensive (it requires construction of multiple functional prototypes), time-consuming (requiring human-subject studies), and inconsistent with the need to construct a robot with sufficient capabilities the first time. In the last few years several techniques have been proposed to address the problem of developing a new conceptual design of a robot in a systematic way (Murphy et al., 2011). There are currently different design approaches for robots interacting with people, depending on the concept availability: (1) robot concept is available à-priori: design consists on replicating an available concept; (2) a new robot concept must be created based on system requirements and environment of deployment; (3) a partial concept is available, as happens on robots resembling a specific form (such as an animal or human form) or with silicon faces closely resembling human faces.

Arroyo (Arroyo et al., 2014) work is a first approach towards the design of a small interactive office robot. He presents a theoretical approach by defining three design guidelines: Functionality, Aesthetics, Interaction. Utility or performance along with functionality is one of the main pillars during the design process of everyday products. Previous research has evidenced that perceived usefulness of a robotic service is one of the main facilitators for the user's initial acceptation. Additionally, the daily exposure of an office robot requires mechanisms to ensure a long-term interaction, otherwise the user will cease using the robot after the novelty effects of its introduction vanishes. They consider that by ensuring functionality as the main design consideration of an office robot, a long-standing bond with the user will be held. Aesthetics, from the product's design perspective is one of the major aspects that influences the response or reaction of people with an object, appliance or system, and it is important for determining if the product is rejected or evokes attraction to people. Particularly, visual aesthetics has a symbolic function that influences how a product is comprehended and evaluated. In the context of an office robot, aesthetics is intrinsically linked to the user, serving as a tool for holding the user's attraction to the robot while evoking strong emotions. He suggests that if aesthetics is considered along with functionality in the entirely design process of the robot, then, it is perceived as being more usable by the target public. Interaction is the design guideline that could differentiate the office robot from any other office machine or supply, because it can generate new user experiences that could attain preference for the robot and achieve a deeper bond with it. Furthermore, the level of interaction determines how a person perceives the robot as a sociable entity, influencing the user's acceptance of the robot.

Eroğlu (Eroğlu et al., 2011) introduces a preliminary study on a new Bioinspired Conceptual Design (BICD) approach. The term "Bioinspired" represents translation of any idea, structure, process, and/or material from biological domain into engineering domain to increase human comfort. Development of a systematic biomimetic/bioinspired design (BID) is challenging for engineers for many reasons, such as: low cost, high efficiency, and high reliability. It is one of the most promising engineering design methodologies to foster engineering creativity and innovation. Advances on the BID methodology may improve engineering design activities, by (1) increasing variety of available technology on engineering domain, (2) reducing cost of the engineering products, (3) designing power/energy efficient and more reliable systems, (4) increasing human comfort, (5) developing environment friendly design (green design), (6) shorter the research and design period and reduce efforts. In his article, Eroğlu introduces a preliminary study on a novel approach to develop a prescriptive bioinspired conceptual design (BICD) process model which is constructed especially for original conceptual design of hybrid bioinspired robots. The BICD steps can be classified with respect to two domains, as engineering and biology. The engineering design process starts with a need. In the same manner, BICD starts with the recognition of the need in the engineering domain. Most widely used technique is to prepare a requirement list to arrange the collected need. Then, problem definition includes specifying the goal, constraints, and criteria. In the problem definition, the criteria are quantifiable objectives to be achieved. The output of this step is the problem statement. After this, overall function of the problem is decomposed into sub-functions. Alternative concepts for the accomplishment of each sub-function are developed and their possible combinations are considered. These combinations form conceptual design alternatives each of which can be represented by a behavioural model. Functional decomposition and behavioural models are used for transformation from engineering domain to biological domain. Selected alternatives should be analysed to answer the questions of "what does it do" and "how does it do". Reverse engineering approach is used for the analysis of biological systems. Mainly, two methods are discussed. In the first method, biologists and literature help to analyse the biological systems alternatives. Secondly, observation and measurements can be done to understand analyse the biological systems. To satisfy the transformation from biological domain to engineering domain, the selected combination of biological systems alternatives should also be decomposed to sub-functions. Then, the second-level biological domain functions can be matched with the engineering domain functions. Desired features of biological systems can be met with morphology (form and structure), behaviour (internal causal process), and function (input-output flow transformation) of biological systems for desired sub-functions. The last step of the BICD is the step of the evaluation of engineering alternatives. Firstly, combinations coming from the different functions should be constructed. Then, the combinations of components can be evaluated by using existing evaluation tool. Finally, by using the outcomes of the tool, a combination can be selected. The selected combination should satisfy all constraints and criteria.

Avalos (Avalos et al., 2015) uses some of the techniques to address the problem of developing a new product in a systematic way and adjust them to carry out the conceptual design of a robot for assistance and rehabilitation of elderly and disabled persons. The degree to which the robot meets the needs for which it was created depends importantly on the quality of the underlying concept. Firstly, Avalos puts the needs identification through surveys and research study then interpreted, organized and translated into a congruent set of customer needs. Then, the engineering specifications of the mechanisms are determined by performing a functional analysis. The functional analysis allows to clearly identifying the functions that the product is intended to accomplish. Having identified the functions, it is necessary to specify criteria to help their easy characterization. These criteria must be assessed objectively, in order to assign levels depending on the available resources, the product needs, or project's target. Finally, for the purpose of weighting these criteria, it is useful to define a degree of flexibility for each. When the functional analysis and the engineering specification of the mechanism have been defined the concept generation process begins. To perform this task, he uses a 3-step method: (1) Separation of sub-problems, (2) Internal and external search, (3) Systematic exploration. To manage the relative complexity of the having multiple possible solutions the methods named Solutions Classification Tree and Combination Table is used. Solutions classification trees help to divide the possible solutions into separate categories. The combination table permits to generate different concepts given the different combinations of solutions of the sub problems. These solutions trees allow visualizing all possible solutions, determining the most promising solutions and discarding those that clearly do not meet the requirements stated in the user's needs list and the engineering specification table. Based on the most promising branches of the classifications trees, a combination table of concepts is constructed. The table combines the possible solutions to the multiple sub problems considered in the functional decomposition. The multiple combinations of solutions are considered resulting in large universe of possible designs of robots. To make the selection of the concept, a comparative scale using a 5-point grading system is used. The points are awarded depending on the level of achievement of the concepts to the user's needs stated. A concept selection matrix is prepared for the assessment of the previously presented designs. This matrix is composed of the selection criteria and concepts generated. Each criterion has a certain weight that defines its relative importance with respect to the others. The selection criteria and weights for each criterion were determined based on the frequency, repeatability of customer needs. The grades given to each concept were given by design team through discussion and voting. Each concept was evaluated with respect to the selection criteria in the selection matrix. In this table a total score is obtained for each concept and the selected concept is the one that gets the highest score.

The traditional engineering design process is to generate a set of high level goals, translate those goals into requirements and then build a functional prototype, with the expectation that a second (or third) prototype will be needed to capture the qualitative aspect of expressiveness or to generate multiple designs on paper, evaluate how well they meet the criteria using some type of scoring (priority matrix), build the version with the highest score, and see if it sufficiently expressive. Both variants fail to capture the overall aesthetics of the design or expressiveness, in part because affect and expressive are generate through motions. **Murphy** (Murphy et al., 2011) proposes a different approach from the traditional design process to embrace experts in creating believable agents. Murphy, due to the lack of affective design principles that force an iterative design process, proposes a three step design process that engages artists in the design process and allows animation to guide physical implementation in order to produce an affective robot without multiple functional prototypes. The incorporation of artists into the design process replaces feedback from users, allowing appropriate affect to be captured with confidence. Animation serves to provide a mechanism for exploring designs but more importantly provides requirements for key components, such as the range and speed of joint motions. These experts have internalized design principles and often work in animation, which can quickly show if the combined range or velocities of joint motion is appropriate. The disadvantage is that designs may not be reflect budgets, physical constraints, or manufacturability. A balance is needed between the artistic and engineering disciplines. The resulting design process consists of three phases: (1) the mechanical designers work with artists exploring designs through animation to achieve an acceptable look and feel, which specifies the degrees of freedom, the general size of the linkages, and the range of motion, velocity, and accelerations for each joint; (2) the second step is to create non-functional, full scale mock-ups out of wood, plastic pipe or other material to simulate linkages and hinges or other hardware to simulate the joints. The non-functional prototypes support checking the overall designs and checking scales and does not require additional expertise; (3) The third step is to use robotics expertise to translate the prototypes into tangible physical designs with actual costs, weights, etc., and then compare designs. This last step guides the creation of an affordable and appropriately constructed device.

System design typically involves the specification of requirements and evaluation of the design with respect to those requirements. For large system designs, the requirements could be too complex to be evaluated by a single analysis tool. In such cases, the coupling of multiple domains and analysis tools is inevitable, and managing these interactions can prove to be difficult, often leading to wasted efforts. **Lattmann** (Lattman et al., 2015) presents an analysis-driven rapid design process for Cyber-Physical Systems that spans multiple domain models and various analysis tools from a wide range of domains, and helps to reduce the design time through the following: (1) revealing and tracking instances of cross-domain coupling, thereby reducing design time; (2) disqualifying non-viable design configurations; and (3) using analysis templates for continuous design evolution with respect to the requirements; minor adjustments to requirements can be done seamlessly, without a complete redesign of the existing reusable analysis templates. In Cyber-Physical System (CPS) design, the specified requirements are related to desired physical and (functional and non-functional) software properties of the system and its sub-systems. Evaluating a CPS with respect to all its requirements can often require performing domain-specific analysis on both the system and sub-system level. Domain-specific analyses are spread across a wide range of domains and tools. Different analysis types require different tools, where each tool targets a narrow range of domains or even a single domain. In a more traditional design process, design teams are divided by domain (e.g., geometric, electrical, software, etc.), with periodic systems integration efforts to synchronize the individual domain concerns. This segregation can allow cross-domain coupling to go unnoticed for some period of time. The process proposed by Lattmann instead reveals and tracks instances of coupling at their genesis by supporting multiple domains and interconnected cross-domain analysis. Disqualification of non-viable design configurations is accomplished by constraint-based discrete design space exploration and by parametric design space exploration. Requirements are implemented as executable analysis templates with a well-defined interface that the design must implement. The utilization of analysis templates makes it possible to quantifiably monitor the design evolution and to satisfy all requirements throughout the entire design process. Minor adjustments to requirements can be done seamlessly, without involving a complete redesign of the existing analysis templates. Finally, analysis templates developed for one application are reusable for solving future design problems in which the requirements or requirement structure are similar.

In the early years of many technical fields, the research community often utilizes a wide range of metrics that are not comparable due to a bias towards application specific measures. The primary difficulty in defining common metrics is the incredibly diverse range of human-robot or robot assisted applications. Thus, although metrics from other fields (HCI, human factors, etc.) can be applied to satisfy specific needs, identifying metrics that can accommodate the entire application space may not be feasible. The absence of standard scales/questionnaires for the subjective assessment of robot-based devices makes it difficult to design products that meet exactly the needs of the intended end users, to further improve prototypes, or to compare the results from different researchers.

Koumpouros (Koumpouros, 2016) study reveals the absence of a standard scale which makes difficult to compare the results from different researchers. Measuring user satisfaction helps to measure the overall quality of a product or service. Tracking user satisfaction during the development phase can help developers and researchers make sure that the changes they are making improve the product/service for users. Two different types of user satisfaction are distinguishable: the processoriented approach (equal to the difference between expected satisfaction and achieved satisfaction) and the outcome-oriented approach (as an attribute extracted from a product or service after its consumption). Subjective assessment records the facts presented by the end user that show his/her perception, understanding, and interpretation of what is happening and therefore measures his/her satisfaction. Attempts to categorize both objective and subjective metrics have been made. According to the USUS Evaluation Framework for Human-Robot Interaction the factors *usability*, *social acceptance*, *user experience*, and *societal impact* are considered the main categories of evaluation factors. Each category is divided into specific metrics, either objectively or subjectively measured. Among these, the authors propose that the following could be tested using end-user questionnaires, which means that they could be considered subjective *Utility*, *Performance Expectancy*, *Effort Expectancy, Attitude towards Using Technology*, *Self-Efficacy, Attachment, Reciprocity, Embodiment, Emotion, Feeling of Security, Coexperience and Societal Impact.* This categorization is the most full and detailed, including aspects that are rarely taken into account when it comes to evaluating a robotic assistant. Choose tailored questionnaires is the rule in robotics assessment. However, the existing variety of questionnaires that could be useful for the assessment of rehabilitation or assistive robot devices is narrow. As derived from the article, QUEST 2.0 may be one questionnaire that can be used in the examined field. Other valuated and relevantly common used questionnaires found in literature are the Assistive Technology Device Predisposition Assessment- Device Form (ATDPA-) and the Psychosocial Impact of Assistive Devices Scale (PIADS). The ATDPA-Device Form is more relevant in context than the PIADS, targeting the evaluation of overall user experience with assistive technology, while PIADS only emphasizes the psychosocial impact of assistive devices, without targeting the evaluation of the actual experience of interacting with a robot device, but rather the impact that this interaction has on quality of life (QoL). Other questionnaires such as the USE-IT questionnaire were ruled out from the very beginning, since they were not well valuated or not widely used from researchers in the bibliography. It seems therefore that a combination of the QUEST 2.0 questionnaire and the Assistive Technology Device Predisposition Assessment- (ATDPA-) Device Form covers most of the desirable user-experience aspects, with ensured validity and reliability. However, no scales have been identified yet in the literature that could be adopted well and measure the individual functionalities of rehabilitation or assistive robot devices. To this end, the authors developed and are currently examining a new scale called PYTHEIA in order to close the gap and help researchers and developers to evaluate, assess, and produce products that satisfy the real needs of the end users. The first results are very satisfactory in terms of their validity and reliability. Based on the findings of the article, in order to further improve the subjective assessment of rehabilitation and assistive robot devices it is necessary for each study to (i) select as subjects the appropriate target group based on clear and valid inclusion criteria, (ii) involve a sufficient number of representative subjects, (iii) analyse statistically the collected data, and (iv) select an established methodology in order to enable comparison between results of different studies.

Robots have been traditionally in operation away from people, for instance in industrial environments. More recently, there has been a trend for bringing robots to market for helping people. There is an urgent need to bring robots into working with people, for people, in the middle of people. However, there are strong design considerations that have to be taken into account for the robots to interact safely with people. Furthermore, operation in demanding environments, such care contest, adds important constraints to the design process, concerning motivation for interaction and safety. Moving robots from controlled environments like laboratories into a dynamic and demanding environment like a paediatric ward of a hospital presents unique robot design challenges, ranging from children safety of interaction to robot engaging appearance and function. The design process followed a rigorous process taking into consideration solution requirements, such as the target audience interacting with robots, or environmental constraints.

Gonçalves (Gonçalves et al., 2015) states that robots design needs to account with several security factors and human-robot interaction features. The shell development process starts by performing an analysis of the environment where the robots will operate, including the deployment space, targeted group of people, and tasks to be executed by the robot, in order to define a set of features taking references on other existing and relevant systems. The placement of the different equipment imposes several constraints, due to their size but also to assure the fulfilment of the desired functionality. Robots must integrate its HRI components guaranteeing that is easy for children to interact with the robot. There are strong design considerations that have to be taken into account for the robots to interact safely with people.

Given the stage of Robots development and use, is observable a lack of standards provided by the International Organization for Standardization to guide their development, ethics ought to be included into the design process of them. In **Van Wynsberghe** (Van Wynsberghe, 2013) article "Designing robots for care: Care centered value-sensitive design" is presented a general framework that may be used by designers and/or ethicists in the ethical evaluation of any care robot first and for the inclusion of ethics in the design of any care robot then. The framework proposed allows for the ethical evaluation of care robots both retrospectively and prospectively. A framework for the ethical evaluation of care robots requires recognition of the specific context of use, the unique needs of users, the tasks for which the robot will be used, as well as the technical capabilities of the robot. Above and beyond a retrospective evaluation of robots, however, Van Wynsberghe says that what is needed is a framework to be used as a tool in the design process of future care robots to ensure the inclusion of ethics in this process. What's more, given the lack of standards provided by the International Organization for Standardization, there exists an opportunity at this time to incorporate ethics into the actual design processes for these kinds of robots. Accordingly, if ethics is to be included in the design process of robots, one must first identify the moral precepts of significance followed by an account as to how to operationalize said precepts. In Peter Asaro's article ''What should we want from a robot ethic?'' (Asaro, 2006), he proposes the three dimensions one could be referring to when one says ''ethics of robots'': (1) the ethical systems built into robots; (2) the ethical systems of people who design robots, and; (3) the ethics of how people treat robots. In particular, the prospective robots in healthcare intended to be included within the conclave of the nurse-patient relationship (care robot) require rigorous ethical reflection to ensure their design and introduction do not impede the promotion of values and the dignity of patients at such a vulnerable and sensitive time in their lives. The goal with Van Wynsberghe framework is threefold: to stimulate ethical reflection of designers/engineers, to encourage ethical reflection from the care ethics tradition, and to illuminate the relationship between the technical content of a care robot and the resulting expression of care values within a care practice. Van Wynsberghe starts from the analisys of Value-sensitive design (VSD). VSD is defined as ''a theoretically grounded approach to the design of technology that accounts for human values in a principled and comprehensive manner throughout the design process'' (Friedman and Kahn, 2003). Value-sensitive design takes as its starting point the belief that technologies embody values (the embedded values approach) and offers a coherent method for evaluating the current design of technologies but also offers a proactive element to influence the design of technologies early on and throughout the design and implementation process. This concept refutes the neutrality thesis of computer systems and software programs which states that such systems are in themselves neutral and depend on the user for acquiring moral status. When said technology is capable of imposing a behaviour on a user, or consequence to using it, the imposing force within the technology is considered a ''built-in'' or ''embedded'' value (or alternatively a disvalue if the computer system hinders the promotion of a value). Technologies may be designed in a way that accounts for values of ethical importance in a systematic way and rigorously works to promote said values through the architecture and/or capabilities of a technology. It follows then that care robots may be designed in a way that promotes the fundamental values in care. When used retrospectively, designers are able to understand the impact of their design on the resulting care practice. When used prospectively, designers are able to incorporate the framework into the design process of a care robot, ultimately incorporating ethics into the design process. There are no (universal) guidelines or standards for the design of robots outside the factory. Designers are given no guidelines pertaining to the inclusion of socially sanctioned ethical principles like safety and/or efficiency, principles which designers still strive for but do so without any standardized means. Van Wynsberghe uses care values as the foundational values to be integrated into a technology and using the elements in care, from the care ethics perspective, as the normative criteria. The resulting approach may be referred to as care centered value-sensitive design (CCVSD). This framework aims to outline the orientation from which one begins in order to develop an ethic of the relationship between care robot and the other actors involved in the care practice. The framework consists of five components: *context, practice, actors involved, type of robot, and manifestation of moral elements*. The framework is intended to be a general outline for the creation of any care robot and not one care robot in particular for one practice in one context. The framework proposed by Van Wynsberghe may be used for both the retrospective and the prospective ethical assessment of care robots and the manner in which the CCVSD methodology occurs differs for each. In other words, it may be used at multiple times throughout the design process of a care robot. For retrospective evaluations using the framework, one identifies the context, practice, actors and the manifestation of moral elements for the practice without the inclusion of a care robot. Following this, one then discusses the type of robot (assistive vs. enabling vs. replacement) and the manner in which the proposed care robot capabilities impact the manifestation of moral elements. As such, the evaluation of the care robot is done on a design-by-design basis according to context and practice. For retrospective analysis, the CCVSD methodology allows one to evaluate the addition of the care robot into a network of actors performing a practice in a specific context. The framework provides a starting point for the interdisciplinary collaboration of a range of robotics researchers—from designers, engineers and computer programmers to ethicists, psychologists and philosophers.

Van Wynsberghe (Van Wynsberghe, 2016), in the article "Service robots, care ethics, and design", shows how CCVSD approach can be used also to evaluate personal and professional service robots. The approach is intended to help robot designers and ethicists in both the retrospective ethical evaluation of care robot design as well as the prospective design of future care robots. Through a series of steps for analysing care practices (involving data collection, analysis and comparisons), the researcher is able to make an ethically grounded judgment concerning the design of a care robot that has the potential to contribute to good care. There are many different layers of ethical issues to be discussed. There are fundamental issues such as: robot responsibility, human responsibility, liability, agency, and well-being. Van Wynsberghe also reflects on more applied ethical issues such as the potential impact on: privacy, security and so on. All of these issues must be dealt with; His dilemma is when, how, and by whom? How can values be included in the design of (care) robots and which values ought to be included? If the ethical evaluation is done at a later stage in development only little tweaks here and there, in the hardware or software, may be possible whereas if the evaluation is done earlier on the entire interface or level of robot autonomy may be altered. To use the framework, i.e. the methodology of the CCVSD approach, the ethicist and roboticist engage in a series of steps: data collection, value analyses, scenario comparisons, and recommendations based on the scenario comparisons. An outline of these steps is presented in Table 1.

Table 1 Steps of the CCVSD methodology Step

Step	What Happens and How
1. Data collection of care practice prior to the robot	1. The researcher uses the components of the framework to paint a picture of the care practice by visiting the context in which the practice occurs and researching relevant literature. This is done prior to the robot's introduction
2. Value Analysis of care practice prior to the robot to create a scenario for comparison	2. The researcher describes in great detail how the care values are manifest in the care practice as well as who has what role and responsibility. The researcher must also have an understanding of how the practice is linked with other practices and with an overall process. The practice is not described in idealistic or utopic terms; rather, the practice is described as it occurs in reality at the time of description. Therefore, the practice is then open to criticism and scrutiny. In this way it is possible to observe when and how a robot may be a welcome, or necessary, addition to the practice for ensuring good care.

3. Data collection of robot	3. The robot is described in terms of its capabilities and appearance. If this step is done without a robot prototype in production it is possible that at this point the design team speculates on the kinds of capabilities and appearance the robot ought to have based on the results of the above two steps.
4. Value analysis of the practice with the robot introduced to create a scenario for comparison	4. The same practice is then described, in as much detail as it was originally described in step 1, only this time once the robot has been integrated. To do this it is optimal for the researcher to visit the context of use to observe the robot in its intended context of use. Oftentimes this is not possible as the robot may still be in an early prototype phase (and as such considered an emerging technology); however, it is still possible to provide a detailed description of the care practice given the way in which the robot is intended to be used. It is also possible that at this step there may be more than one robot prototype to enter the practice. Each of these prototypes ought to be integrated into a separate scenario to show the differing results to the resulting care practice
5. Scenario comparison	5. At this point one has an elaborate picture of the care practice, in terms of the manifestation of values, before the robot has been introduced and following the robot's inclusion. With this information one can now compare analyses according to the impact on: the distribution of roles and responsibilities, the impact on human-human relationships, the generation of new human-robot interactions, and the impact on the care values (either positive or negative). If there are multiple robot prototypes each of these scenarios will be compared with the

	scenario of the care practice prior to the robot's inclusion. If there is only one robot prototype, then there ought to be two scenarios for inclusion.
6. Recommendations for design, re-design, implementation, and/or policy	6. Depending on the stage of development, the analysis can yield recommendations for different stakeholders. If the analysis is done earlier on in the design process recommendations can be used to steer future prototypes. If the evaluation is done later on recommendations may be used to steer implementation and policy to regulate the robot

The ethical tradition that serves as the normative foundation for this approach is care ethics. This tradition is neither consequentialist (i.e. the consequences of an action determine if it is right/wrong) nor deontological (i.e. adhering to a duty determines if an action is right/wrong). Care ethicists claim that care ethics presents different elements that act as a starting point for uncovering and exploring a moral dilemma. Central to these elements are: relationships, roles, and responsibilities. In particular, the reciprocal nature of a relationship is highlighted which facilitates an active, rather than a passive, role of the care receiver. From this standpoint then, the ethical dimension of the Care Centred (CC) framework, and the CCVSD approach overall, is not to focus entirely on the consequences of the robot's actions nor to focus on certain duties that the engineer must abide by, or the robot must adhere to; rather, the approach echoes the care ethics perspective in that it focuses on promoting values inherent in the relationships, roles, and responsibilities of the practice at hand. Most importantly, it focuses on the relational nature of care activities. What's more, care ethics argues that roles, relationships and responsibilities mark the starting point for the ethical analysis (rather than providing an equation or the like for solving an ethical dilemma). Accordingly, Van Wynsberghe suggests that the CC framework acts as a starting point for identifying the ethical issues relevant to the robot in question. From the starting point of roles, relationships and responsibilities, both the consequences and duties must be weighed to come to an answer about the right thing to do, i.e. what is right/good. The ethical dimension of the robot, its goodness or badness, is not entirely based on how it may increase efficiency (i.e. consequence driven) or protect the privacy of users (i.e. duty driven) but also on how it will impact the ethical character development of users (e.g. will it have a long term effect of causing users to objectify other humans?). The CCVSD approach requires that certain conditions are met in order to make a retrospective evaluation. These conditions are derived from the conditions for labelling a care practice as such and are: (1) That the practice be a response to the needs of another and, (2) that the care giver and care receiver be engaged in a reciprocal interaction.

13.4 Conclusion

System Design is both a scientific and a creative process. In the last few years several techniques have been proposed to address the problem of developing a new conceptual design of a robot in a systematic way.

From this literature survey, it can be seen how the design process of robots mainly consists of four phases: (1) need identification, i.e. system functional specifications, (2) identification of subsystem technical specifications, (3) evaluation of the technical specifications and selection of the most suitable to meet functional requirements, (4) evaluation of the whole system both from the user satisfaction and ethical point of view.

The need identification phase can be done using the data of surveys as well as a research study performed in situ where the robot will be used and then interpreted, organized and translated into a congruent set of customer needs (Avalos et al., 2015), following a theoretical approach by defining three design guidelines: Functionality, Aesthetics, Interaction (Arroyo et al., 2014) or including artists, especially animators and theatre experts who work with the design of believable agents in order to ameliorate the technical and economic risks associated with the design of affective robots.

The technical specifications definition has been done through different solutions. One possible solution is to develop concepts of hybrid bioinspired robots is the Bioinspired Conceptual Design approach: a hybrid bioinspired robot is designed by inspiring multiple biological systems performing different functions behaviours with a straightforward mapping between biological domain and engineering domain (Eroğlu et al., 2011). Another solution is to translate the needs into a set of technical requirements using a functional decomposition technique; a mixed methodology of function classification trees combined with a concept combination tables is used to explore and develop a series of robot concepts that could satisfy the technical requirements and functions. Using a structured framework for product development, a multilinked concept is found to be the robot design that best suits the needs detected. (Avalos et al., 2015).

The selection is obtained by evaluating the different concepts against the set of user needs initially established. Finally, the structured methodology employed allows for the development and design of a singular product by exploring a large set of possible designs and allowing for a costumer based product with high levels of user satisfaction (Avalos et al., 2015). Another way to select the technical specifications can be the use of existing evaluation tools (Eroğlu et al., 2011) or developing new evaluation tool that help the collaborative learning process supporting multiple domains and interconnected cross domain analysis (Lattman et al., 2015). Lattman describes an analysis-driven rapid design process for Cyber-Physical Systems. This design process supports multi-domain *Component* models and *Set of Test Benches*, which aid designers in revealing and tracking cross-domain coupling. This approach includes simulation and non-simulation based analysis templates, which are directly mapped to requirements. These *Test Benches* support continuous use of analysis templates for design evolution with respect to the requirements. Refinement of designs (i.e., *Component Assemblies*) and *Design Spaces* with constraint-based architecture exploration facilitates the disqualification of non-viable design configurations. Since their approach is completely independent of the application domain(s) and corresponding analysis tools, it could be adopted to accelerate any kind of model-based development.

For the evaluation of design process system, most of the studies found in literature uses either custom-made questionnaires or interviews that are neither valid nor reliable instruments to represent the subjective opinion and perception of the end users. There is therefore a great gap in the subjective assessment of rehabilitation or assistive robot devices. The absence of standard scales/questionnaires for the subjective assessment of robot-based devices makes it difficult to design products that meet exactly the needs of the intended end users, to further improve prototypes, or to compare the results from different researchers. Based on the findings of the review, in order to further improve the subjective assessment of rehabilitation and assistive robot devices it is necessary for each study to (i) select as subjects the appropriate target group based on clear and valid inclusion criteria, (ii) involve a sufficient number of representative subjects, (iii) analyse statistically the collected data, and (iv) select an established methodology in order to enable comparison between results of di different studies (Koumpouros et al., 2016).

Regarding the ethical constrain, there are strong design considerations that have to be taken into account for the robots to interact safely with people. Furthermore, operation in demanding environments, adds important constraints to the design process, concerning motivation for interaction and safety. Gonçalves (Gonçalves et al., 2015) presents a robot shell design development process easily extendable, and hence employable to design robots with different shapes in many other application scenarios, particularly on human assistance robots' design. The prospective robots in healthcare intended to be included within the conclave of the nurse-patient relationship require rigorous ethical reflection to ensure that their design and introduction do not impede the promotion of values and the dignity of patients at such a vulnerable and sensitive time in their lives. The ethical evaluation of care robots requires insight into the values at stake in the healthcare tradition. What's more, given the stage of their development and the lack of standards to guide their development, ethics ought to be included within the design process of such robots. The manner in which this may be accomplished, as presented in Van Wynsberghe paper (Van Wynsberghe, 2013), uses the blueprint of the Value-sensitive design approach as a means for creating a framework tailored to care contexts. Using care values as the foundational values to be integrated into a technology and using the elements in care as the normative criteria, the resulting approach is referred to here as ''care centered value-sensitive design''. The care centered framework is meant to indicate and direct the evaluator to the necessary components in care from a care orientation. The CCVSD methodology is meant to provide a guideline for analysis of a practice with and without the use of a care robot. Using the CCVSD methodology to compare two care robots used for the same practice with different capabilities, allows us to envision the resulting care practice in terms of the robot's impact on care values as well as the robot's potential impact on care in the holistic sense. The significance of Van Wynsberghe work comes from the stage of development of care robots and the belief that ethics may be included at this time in the design process to foster trust between the public and the resulting robots. The framework provides a starting point for the interdisciplinary collaboration of a range of robotics researchers, from designers, engineers and computer programmers to ethicists, psychologists and philosophers. Within the coming years it should not be a surprise to encounter either a personal or a professional service robot in our homes and/or our work places. Since these robots will function in the unpredictable, unstructured environment that humans live and work in, they demand ethical reflection. Van Wynsberghe argues that the ethical evaluation should be specific to the robot (its capabilities and appearance) and the practice within which is has been placed. More specifically Van Wynsberghe suggests that features of both the robot and the practice will help to decide if that robot is good or bad for the practice at hand.

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