A survey of values, technologies and contexts in pervasive healthcare

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ABSTRACT

We argue that pervasive computing technologies for elderly care can have beneficial and harmful ethical implications. At the heart of these ethical implications lie the effects technologies have on human values, such as well-being, autonomy and privacy. A technology's functions influence how it affects values. These functions are the result of design decisions. So, design can play a part in dealing with ethical implications. We argue that by understanding the relationship between values and technologies in this domain, designers will be in a better position to account for values explicitly, and hence address ethical implications, throughout design. To foster such an understanding, we survey literature on pervasive computing for elderly care, and identify values, technologies and contexts discussed there. We develop a taxonomy to categorize our findings, which serves as a basis to identify and analyze relationships between values, technologies and contexts in pervasive computing for elderly care. With this analysis, we aim to help designers consider the ethical implications of their designs.

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1. Introduction

It is not unusual for an article on pervasive computing to begin by asserting that pervasive computing technologies hold the promise to help older adults maintain their independence, by supporting them in their daily activities, improving their safety and quality of life, while enabling them to remain living comfortably in their own home as long as possible, “aging in place”. In living up to this promise, pervasive computing is likely to contribute to the good of many older adults, and benefit society at large by addressing some of the challenges of an aging population. In other words, these technologies have moral or ethical implications; their contribution to the well-being of older adults is good, and helping older adults maintain their independence is the right thing to do. Pervasive computing technologies can also have less desirable ethical implications, such as privacy concerns and loss of autonomy [1].

Such ethical implications center on pervasive computing technologies’ role in supporting or hindering human values. For example, the broad aims of many pervasive computing technologies for elderly care are based on human values, such as independence, safety and well-being. Some of pervasive computing’s negative ethical implications have to do with human values, such as privacy and autonomy. Values can be defined broadly as “what a person or group of people consider important in life” [2]. Examples of values include human welfare, fairness, justice, privacy, accountability, and autonomy. It is when a technology affects values favorably (for example, improves quality of life) or adversely (for example, violates privacy)
that ethical issues arise. Technologies affect values by providing or performing functions that make possible or support some actions, and not others. A fall detection system might enhance (positively affect) an older adult’s safety by notifying caregivers of falls. The same fall detection system, if it captures images of the older adult, might diminish (negatively affect) that person’s privacy.

Though a technology’s effects on values occur in the context of use, they begin to take shape earlier. During design, designers make decisions on which functions a technology will include, and which it will not. Designers also decide how the technology will provide these functions (for example, fall detection using an accelerometer instead of a camera). Since these functions play an important role in how a technology affects various values, and designers make fundamental decisions about these functions, designers arguably play a part in shaping how a technology will affect various values, with potential ethical implications. In some cases, they do so explicitly, for example, aiming to help older adults maintain their independence. In other cases, the effect the technology has might not be apparent until it is put to use. Either way, designers play a part.

Considering that design decisions influence pervasive computing technologies’ effects on a range human values, and thus their ethical implications, relevant values should be taken into account during design. To make values a design consideration, a designer needs to have a definition of values, some awareness of values already at play in pervasive computing and elderly care, a way to identify and analyze yet unaddressed values in this field and tensions among them, and an understanding of the mechanisms through which various technological features affect values. Values, and their relationship with technology, are not necessarily familiar concepts to designers in this field. Nor are ways of dealing with them.

Value Sensitive Design (VSD) is an established approach for addressing human values throughout a technical design and implementation process [2]. It offers a range of techniques to identify and analyze a technology’s stakeholders and their values. It has been applied in a range of domains, including ubiquitous computing [3]. To our knowledge, it has not been applied in the area of pervasive computing for elderly care. Furthermore, VSD has not been used to examine the relationships between values and the functions provided by pervasive computing technologies for elderly care. Values, such as privacy and trust, do receive a fair amount of attention in research on pervasive computing, but they are often discussed in individually and within the scope of a specific project (for example, privacy concerns that arose in evaluating a fall detection system). To gain an understanding of the many values at play in this domain, the relationships between them, and the ways in which various pervasive computing technologies affect them, one would have to assimilate discussions of values that are spread out in research papers across this field.

We aim to provide an overview of the values at play, and relationships between these values and the technologies being developed in pervasive computing for elderly care. We argue that by understanding these relationships, designers will be in a better position to account for values explicitly throughout design. We develop this overview by identifying values, technologies and their contexts in this field. Using concepts and techniques from VSD, we survey literature on pervasive computing for elderly care, identifying stakeholders, explicitly supported values, and the ways in which these are affected. We identify the technologies that contribute to applications in this field, and the contexts in which they are used. We present a taxonomy that consists of different categories of values, technologies and contexts, which we used to classify the entities we identify. We use this taxonomy as a basis for identifying and analyzing relationships between values, technologies and contexts in pervasive computing for elderly care.

This paper is organized as follows. In Section 2, we describe our approach. We introduce Value Sensitive Design and describe how it can be used as an analytical tool. We also discuss a literature survey we conducted as a starting point for our analysis, as well as the taxonomy we developed to support our analysis. In Section 3, we present the results of our literature survey and classification in our taxonomy. In Section 4, we discuss our analysis of relationships between values, technologies and contexts in pervasive computing for elderly care. We present our conclusions and suggestions for future work in Section 5.

2. Approach

2.1. Value Sensitive Design

We use a number of key concepts from the Value Sensitive Design (VSD) framework to help identify values, technologies and contexts of use in pervasive computing for health care, and relationships among them. VSD is an approach to technology design that aims to account for human values systematically throughout the design process [4]. VSD uses conceptual, empirical and technical investigations to discover and define values, and analyze how existing technologies affect these values, or design new technologies to support values. Throughout these investigations, VSD uses a number of key concepts that our relevant to our present work, namely stakeholders, values and potential benefits and harms.

VSD defines values broadly as “what a person or group of people consider important in life” [2]. Work on VSD often focuses on moral values, such as human welfare, trust, privacy and accountability [2]. VSD takes an interactional stance on values, which holds that values are neither solely determined by technology nor by social systems in which technology is deployed and used, but through the interaction of both [5]. That is, technological development is influenced by people and the social systems they are part of, and technologies contribute to shaping individual behavior and social systems. VSD distinguishes between explicitly supported, stakeholder and designer values [6]. Explicitly supported values are those a technology aims to support. For example, a fall detection system explicitly aims to enhance its users’ safety. Stakeholder values are those
held by the stakeholders of a technology. A technology can affect these values, though they are not necessarily considered (or even known) during design. For example, users of a fall detection system that uses cameras might feel that the system invades their privacy. Finally, designer values are those a designer holds, which are not necessarily expressed, and often guide designers' decision making subtly, without their awareness. For example, someone designing a fall detection algorithm might choose to favor false positives (the user does not fall, but the algorithm detects a fall) over false negatives (the person falls, but the algorithm does not detect a fall), on the implicit grounds that “it is better to be safe than sorry”. This decision involves a value-judgment, rather than a factual one (cf. [7]), and is guided by the designers’ values.

Stakeholders are another key VSD concept that we use here. VSD distinguishes between direct and indirect stakeholders. Direct stakeholders are the individuals who interact directly with the technology or the technology's output. Indirect stakeholders are those who do not interact with the technology (or its output) directly, but are affected by it. The latter group is often overlooked in the design of technology, which understandably focuses on direct users.

VSD identifies and accounts for these concepts using conceptual, empirical and technical investigations iteratively and integratively. Conceptual investigations focus on identifying which direct and indirect stakeholders are affected by a technology and what values are implicated. In these investigations, the designer can identify benefits and harms that the technology potentially poses to its stakeholders. Designers can use these harms and benefits to identify underlying values, and tensions between the values. Subsequently, designers can use relevant literature to define the identified values. Conceptual investigations are informed by empirical investigations of the technology's context. Empirical investigations can take many forms as “the entire range of quantitative and qualitative methods used in social science research is potentially applicable” [2]. Finally, technical investigations assess how existing technologies support or hinder human values. Technologies provide certain “value suitabilities” [2], which technical investigations examine. Alternatively, technical investigations can consist of designing a system to support selected human values.

We use a combination of conceptual and technical investigations to identify direct and indirect stakeholders and values in pervasive computing for health care, and examine how technologies in this field affect those values. Our focus here is on explicitly supported values, as the main source of our analysis is pervasive computing literature.

2.2. Literature survey

We need sources from which to identify values, technologies and contexts in pervasive computing for health care. We used academic literature on pervasive computing as a starting point, as it is a useful way of getting an overview of the state of the art in this field. Moreover, literature describes technologies at a level of detail that is conducive to our analysis. We selected academic journals that focus on pervasive computing, or related research topics including ubiquitous computing, ambient intelligence, smart environments and internet of things, as well as human–computer interaction. Our selection included Personal and Ubiquitous Computing; Pervasive and Mobile Computing; IEEE Pervasive Computing; International Journal of Ubiquitous Computing; Interacting with Computers; Human–Computer Interaction; and International Journal of Human–Computer Studies.

We searched these journals’ archives to find articles that fit our focus, using the following keywords: independent living; (ambient) assisted living; aging in place, at home, or gracefully; elderly care; eldercare; health care for elderly; assistive technology; supporting activities of daily life. To ensure that articles in the human–computer interaction journals we selected fit the overall area of pervasive computing and related research topics, we searched using keywords ubiquitous computing; pervasive computing; internet of things; physical computing; smart homes; ambient intelligence; intelligent environments; smart environments; post-desktop computing; embedded computing; and sensor networks. We opted to limit our selection to articles published from 2000 onwards, because, with the exception of Personal and Ubiquitous Computing (known as Personal Technologies from 1997 to 2000), the journals in our selection that focus on Pervasive Computing and related topics explicitly did not emerge until the 2000s. Furthermore, the human–computer interaction journals in our selection feature two or fewer articles on pervasive computing or related topics prior to 2000.

We refined the selection of articles by scanning their abstracts for terms related to the application domain, elderly care (which we listed in the previous paragraph) and for mention of an application or technology. We scanned the remaining articles for mention of human values, using the definition we presented in Section 2.1 as a guide. We also used a heuristic list of values often implicated in system design presented in [2], which consists of: human welfare, ownership and property, privacy, freedom from bias, universal usability, trust, autonomy, informed consent, accountability, courtesy, identity, calmness, and environmental sustainability. This list provides definitions of those values, as well as references to examples of relevant literature, which aided the selection process. This yielded a group of papers on pervasive computing and related research topics that presented a technology in the elderly care domain, and discussed one or more human values. We used this selection as a source for our analysis.

2.3. Taxonomy

The process we described in Section 2.2 yielded a selection of articles that serves as a source to analyze relationships among values, technologies and contexts in pervasive computing for elderly care. The first step in this analysis is to identify individual values, technologies and contexts described in each of the articles. We group these individual entities in a
Table 1
Initial list of values.

<table>
<thead>
<tr>
<th>Safety</th>
<th>Health</th>
<th>Comfort</th>
<th>Well-being</th>
<th>Independence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality of Life</td>
<td>Autonomy</td>
<td>Privacy</td>
<td>Informed consent</td>
<td>Reduced isolation</td>
</tr>
<tr>
<td>Freedom</td>
<td>Dignity</td>
<td>Duty of care</td>
<td>Responsibility</td>
<td>Sociality</td>
</tr>
<tr>
<td>Mobility</td>
<td>Social stigma</td>
<td>Anonymity</td>
<td>Acceptability</td>
<td>Awareness</td>
</tr>
<tr>
<td>Self-efficacy</td>
<td>Assistance</td>
<td>Social Inclusion</td>
<td>Trustworthiness</td>
<td>Transparency</td>
</tr>
<tr>
<td>Peace of mind</td>
<td>Remembering</td>
<td>Social contact</td>
<td>Security</td>
<td>Social acceptability</td>
</tr>
<tr>
<td>Social welfare</td>
<td>Accountability</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2
Value categories.

<table>
<thead>
<tr>
<th>Value category</th>
<th>Identified values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical well-being</td>
<td>Quality of life, health, comfort</td>
</tr>
<tr>
<td>Social well-being</td>
<td>Social welfare, social stigma, social inclusion, social contact, sociability, reduced isolation, social acceptability</td>
</tr>
<tr>
<td>Freedom</td>
<td>Freedom, mobility, autonomy, independence</td>
</tr>
<tr>
<td>Privacy</td>
<td>Privacy, informed consent, anonymity</td>
</tr>
<tr>
<td>Responsibility</td>
<td>Accountability, duty of care, responsibility</td>
</tr>
<tr>
<td>Safety</td>
<td>Safety, security</td>
</tr>
</tbody>
</table>

taxonomy of values, technologies and contexts, based on common characteristics. Using these groups as a starting point, we analyze recurrent relationships between values, technologies and contexts in pervasive computing for elderly care.

To identify values in the articles we selected, we used the definition of values given in Section 2.1 and used the heuristic list of values (and definitions of those values) described in Section 2.2 as starting points. Table 1 lists the values we initially identified. The next step was to group similar values to create categories of values. To guide this process, we turned to Cheng and Fleischmann’s meta-inventory of values, which builds on a review of research to date on values in a range of fields including psychology, sociology, anthropology, science and technology studies, and information science, and a review of 12 prominent value inventories developed within those fields [8]. The meta-inventory consists of 16 categories of values: freedom, helpfulness, accomplishment, honesty, self-respect, broad-mindedness, creativity, equality, intelligence, responsibility, social order, wealth, competence, justice, security and spirituality. Further categories that occurred in fewer than 5 of the inventories they reviewed include health, social relationship, trust, a comfortable life, and privacy.

Based on this, we created the categories of values listed in Table 2. The values grouped under physical well-being correspond roughly to the meta-inventory category helpfulness, as it includes the values human welfare (which is defined in terms of physical well-being in the heuristic list presented in Section 2.1) and the good life, and to the health category. We rephrased the meta-inventory category of social relationship as social well-being, to cover the wider range of related concepts we encountered. The safety category corresponds roughly to the meta-inventory category security, but we rephrased it to avoid confusion with information security, which is an often-addressed topic in pervasive computing. The freedom, privacy, and responsibility categories correspond to the meta-inventory categories of the same names. The remaining values we encountered (self-efficacy, remembering, trustworthiness, and transparency) are not sufficiently similar to any of aforementioned categories to warrant inclusion in them. As these values are each mentioned in fewer than three of the papers included in our survey, we did not create categories for them.

We take a similar approach to identify and group technologies, which is the second dimension of our taxonomy. First, we examine the selection of literature for mention of technologies, including hardware, software, applications and/or architectures. We use Cook and colleagues’ [9] survey and classification of the technologies that comprise ambient intelligence to guide the categorization of the technologies we encountered. Their classification is useful for our aims here, as it covers both hardware and software at a level of technical detail that can help in analyzing how technologies affect values in this domain. Cook and colleagues identify five key technologies that contribute to ambient intelligence: sensing, reasoning, acting, security and HCI. They identify a number of types of reasoning, namely user modeling, activity prediction and recognition, decision making, and spatiotemporal reasoning, which we treat separately here. Cook and colleagues’ HCI category consists of context awareness and natural interfaces. We include graphical user interfaces (GUIs) in this category, as eight of the articles in our survey discuss pervasive computing applications that include a GUI. We do not discuss the natural interfaces category, as only two of the articles in our survey discussed interfaces that fell within this category, and did so too briefly to contribute to our analysis. We do not discuss the acting or security categories, as we encountered fewer than three papers that presented technologies that fell within each of these categories.

The third dimension of our taxonomy is contexts of use, which we include because values can be defined differently in different contexts, and technologies can have different applications in different contexts. The view of context of use we take in our taxonomy draws on the components of context of use analysis presented in [10], which consist broadly of stakeholders, users, tasks, and environments. In line with the view of stakeholders we presented in Section 2.1, we consider users to be direct stakeholders of a system. Accordingly, the context of use dimension of our taxonomy consists of stakeholders, goals or tasks, and environment. This dimension allows us to categorize the technologies we surveyed according to who uses them or is affected by them, which activities the technologies support, and the social and physical environment in which the technologies are embedded.
3. Taxonomy

3.1. Values

3.1.1. Physical well-being

One aspect of physical well-being that is frequently mentioned in the literature we surveyed is quality of life. Quality of life is presented as a condition of elders that can be enhanced, improved or increased [11–21], or hampered, diminished or decreased [13,22,23,20]. Improvement is considered to come from applications and services, where as decreased quality of life comes from health risks (e.g., falls [22] or obesity [20]), difficulties caused by dementia [23], blood pressure monitoring [16]. Though the term is used frequently in the literature we surveyed, we did not encounter any definitions.

Comfort is similarly presented as an aspect of elders’ lives that can be enhanced [24], improved [21], ensured [15], and felt [16,18]. It can also be jeopardized [24]. In the latter case, living in one’s own home is identified as a potential cause. In the other cases, comfort can result from services that technologies provide, or directly from hardware (in cases where it is comfortable or uncomfortable to wear). As with quality of life, we did not encounter definitions of comfort.

We also included health in the physical well-being category. Health is described as something that can be monitored [24,11,16,18,20,21], improved, aided or benefited [25,26], at risk or hazard [22,19,27], has a status or state [28,16,1,29,21], can have problems [28], can decline [15,30,21] and can have complications [31]. We did not find explicit definitions of health in the literature.

3.1.2. Social well-being

In the literature we surveyed, social well-being is often discussed in terms of social contact or connection, social bonding and socializing, and is valued by older adults or their relatives or caregivers [13,14,28,25,1,26,18]. Social contact or connection is described as something that can be facilitated [14,18], stimulated or promoted [28], and created [26]. It is discussed as a connection between elders and their (remote) relatives [14,28,1,18]. Social well-being is adversely affected by social isolation, which can stem from difficulties related to cognitive impairments or dementia [13,23], old age [26,18], or living away from offspring [20]. Social isolation, and related loneliness, could be reduced by fostering social connection [26]. Another aspect of social well-being, related to use of technology, is social stigma technology brings [13,1] or, conversely, technology's social acceptability [30].

3.1.3. Freedom

The freedom category of the values dimension of our taxonomy includes the value of independence. Independence receives a considerable amount of attention in pervasive computing for elder care, as many of the technologies in this domain focus on helping elders live independently. Accordingly, it is seen to be a value held by older adults. Though independence is not explicitly defined in the literature we surveyed, much of its meaning can be deduced from the ways in which the term is used. Independence is frequently presented as an aspect or way of living one’s life (e.g., “living independently”) [11,13,22,28,23,15,32,1,17,19,20]. Independence is often discussed in conjunction with the idea of living in one’s own home [24,14,23,32,1,14,15,20,21], which suggests this is considered an important aspect of independence. Independence can also refer to independence from caregivers or physician visits [20]. Performing basic activities of everyday living (e.g., bathing and eating) and instrumental activities of daily living (e.g., cooking healthy meals and doing laundry) on one’s own (i.e., independently) is a precondition of independence in everyday life [33,25,1,21].

The literature we surveyed mentions a variety of ways in which independence can be affected. It can be facilitated, supported or assisted [23,25,18–20], maintained [11,1,26,34], increased or improved [12–14,28,15,32], and promoted [33]. Independence can be hindered by (the consequences of) falls [22,19], cognitive impairments or dementia [13,14,28,33,34], long-term blood pressure monitoring [16], and diseases and disabilities associated with aging [17,26,20]. Notably, [1] mentions that overreliance on technology causes one to disuse one’s competences, which can adversely affect independence. Tensions can exist between independence and safety, in that living independently can pose challenges to safety [15]; and between independence and privacy, when technologies to support independent living adversely affect privacy [1].

Autonomy is a similar concept, and is often used interchangeably with independence. Unlike independence, we did encounter a definition of autonomy in the literature: the right to self-determination [18]. Like independence, autonomy has the precondition that one can perform (basic and instrumental) activities of daily living on one’s own [33,1,21], or can self-manage one’s life [20]. Autonomy can be increased, improved or enhanced [12,14,33,17,20]. It can be promoted by aging-in-place [21]. Autonomy can also be lost when one is (physically) dependent on technology or receives too much support [1]. One’s autonomy can be violated if one’s activities are curtailed, or if one perceives or fears curtailment (and thus does not engage in those activities) [18].

3.1.4. Privacy

Privacy is a widely recognized value in this domain. The literature we surveyed discusses privacy exclusively as a value held by older adults. Privacy is described as “a socially constructed value that differs significantly across environments and age cohorts of individuals” [18, p. 2]. In the area of home-based computing, privacy has been defined as seclusion (the right to be left alone); autonomy (the right to self-determination, which is violated through chilling effects when people
do not engage in certain activities for fear of surveillance); property (the right to determine the uses and dissemination of personal information); a spatial construct or location privacy (establishing and respecting boundaries); and data protection (generated data are subject to consent to use and correction by the individual) [18]. Discussions of privacy in the literature we surveyed suggest that it can be preserved, enhanced, ensured, respected or maintained [12, 35, 36, 19, 27]. It can also be given up, sacrificed, compromised, invaded, or impinged on [12, 22, 18, 19]. Furthermore, the literature mentions privacy constraints [12], privacy concerns [13, 30, 1], privacy issues [32, 36, 29], privacy implications [1], and privacy related conflicts [20]. In addition, privacy constraints [12], privacy levels [35], and privacy requirements [29] are mentioned.

Giving up or sacrificing one’s privacy is associated with subjecting oneself to observation [12]. More specifically, people’s privacy is said to be compromised by capturing images of them [22, 19]. Accordingly, privacy concerns or issues are raised by exposing one’s identity [13, 15] and by visual and auditory sensing [30, 32, 1, 36].

Privacy is said to be preserved, maintained or enhanced by having full control of the type of information that different people can access, only disclosing the right information to the right people [12, 35], and by not being able to identify people from information [12, 13, 15, 32, 36, 27, 29]. Another way of avoiding conflicts is getting people’s informed consent [20].

It is argued that usefulness of a technology with respect to individuals’ own lives plays a role in determining how they think about privacy with regards to that technology—the more useful it is, the more willing individuals are to accept privacy implications [1, 18]. Data granularity or level of intrusion, along with particular reasons for collecting information, have also been found to play a role in individuals’ acceptance of privacy implications [1, 18]. Furthermore, activity sensitivity (i.e., potentially sensitive behaviors such as sex) has been found to be an important factor, more so than spatial privacy [18]. It is also suggested that data recipients, that is, who can access sensitive information, are an important aspect of privacy [12, 35, 31, 1, 18, 29].

3.1.5. Responsibility

In the literature we surveyed, the concept of responsibility was most commonly used to convey that a certain hardware (e.g., a mobile device or a sensor) or software component (e.g., a software agent, an application, or a server) has a certain role to perform (e.g., collecting data) [11, 12, 35, 14, 16, 32, 29, 20]. In some cases, it referred an individual’s role or duty to do something (e.g., a caregiver’s duty to do something) [23, 34, 27, 29], or to assume a duty (take responsibility for caring for one’s own health) [28]. The term tasks was used to convey the same notion with regards to software or hardware components [24, 11, 12, 32]. With regards to individuals, the concept of task was generally used to refer to (household) activities to be done or performed by an individual as part of everyday life (e.g., washing hands) [14, 33, 23, 17, 26, 34, 27, 20], or as part of a job or role (e.g., caring tasks) [35]. The term “duty” was used in the same sense, exclusively with regards to caregivers [14, 27].

3.1.6. Safety

In the literature we surveyed, safety (occasionally referred to as security) is most frequently discussed as a value held by older adults, (e.g., “the safety of elders”) [24, 12, 32, 1, 37, 36, 19, 18, 20, 21] or people with dementia [13, 14, 34, 27], and as a value of caregivers or relatives of older adults (e.g., “family members’ desire to keep elders safe”) [1, 18]. The term “safe” is also used to describe a living condition (e.g., “live safely”) [15, 17], and as a condition of an individual’s environment or context (e.g., “a safe living environment”) [15, 32, 20].

One can experience feelings of safety or a sense of security [14, 19, 20]. Safety (or feelings thereof) can be enhanced [24, 17, 36, 18], improved [12, 21], increased [32, 20], guaranteed [24], and ensured [15, 1, 27]. On the other hand, safety can be jeopardized [24] or abrogated [18]. Also, one can stay safe [12] or keep (others) safe [1].

The literature suggests that safety is hindered by (health) risks, harm, hazards, hazardous situations, danger, dangerous events or situations, emergencies or emergency situations, being trouble, and experiencing problems [24, 12, 14, 15, 32, 37, 36, 34, 19, 18, 27]. These challenges to safety can stem from a variety of issues, including falls and related injuries [24, 12, 32, 1, 36, 19, 18, 21], unattended events and incomplete activities [15, 32, 37], navigation problems such as wandering [13, 14, 27].

The literature mentions relationships between safety and other values. [15] uses the term “independent but safe living”, which suggests that independent living can challenge safety. It has also been argued that individuals might be willing to accept some invasion of their privacy for safety reasons [12, 18], suggesting that in some situations safety outweighs privacy.

3.2. Technologies

3.2.1. Sensing

Generally speaking, sensors enable pervasive computing applications to gather sensory data from the physical environment in which they are situated. Anonymous, binary (‘on’ or ‘off’) sensors attached to household objects or infrastructure, such as movement detectors, door sensors, contact switch sensors and pressure pads can be used to detect or locate a person’s presence in a room or on furniture, or to detect people’s interactions with household objects (e.g., a water kettle) as they perform activities [12, 14, 23, 15, 32, 17, 37, 21]. [30] uses user-worn magnetic sensors to detect magnetic fields emitted by electronic devices with which the user interacts.

Body-worn accelerometers can provide information on a person’s body movement, which can be used to detect falls or assess levels of physical activity [24, 11, 22, 32, 26]. Imaging sensors (including thermal imaging [19] and 3D sensors [36]) can
also be used to gather information on body movement such as posture, position and velocity, which is useful in fall detection applications [24,32,1,18].

Sensors for temperature, blood pressure, pulse, blood-oxygen ratios, ECG or glucometers can be used to gather an individual’s vital statistics, for use in health monitoring applications [31,16,29,20]. Temperature, noise and light sensors can provide information on the state of the user’s environment, which can help applications that take the user’s context or situation into account [17,29].

NFC/RFID tags and QR codes can be used to uniquely identify and locate tagged objects (e.g., a teacup’s presence on a tray), or to store (a link to) relevant information (e.g., medication instructions) [35,28,33]. Similarly, Bluetooth or modulated illumination-based beacons deployed throughout the user’s environment can be used to transmit unique location identification codes, which a hand-held device or user-worn “badge” can detect in order to locate the user [13,27]. GPS can also be used to determine location [11,12].

3.2.2. Modeling

Many pervasive computing applications for health care use models of user behavior to adapt the software to the user, and as a baseline from which to detect anomalies or changes in the individual’s behavior patterns. We encountered a distinction between models that are specified (or predetermined) based on what we can loosely call “domain knowledge”, and those that are built from collected sensor data. The most basic form of the former sets thresholds that specify which input data correspond to “normal” behavior or situations, and which correspond to “abnormal” behavior or situations (e.g., an excessive period of inactivity after a fall) [24,22,36,26,19]. Similarly, rules can specify actions to take under certain conditions (e.g., sensor readings indicative of arrhythmia) or at specific times [11,14,27,20]. Other applications use ontologies to model user activities as primitive actions or behaviors and associated contexts, and specify which sensors indicate user interaction with those contexts [23,15,32,17].

Another group of applications (automatically) builds or learns activity models from data sources including room occupancy statistics gathered from sensors [12,21], features extracted from sensor data [30], and descriptions of activities and relevant objects mined from the Web [37].

3.2.3. Activity prediction and recognition

A number of applications in our survey use different types of sensor information, activity models and reasoning to infer what the user is doing. Several applications take a rule-based approach to recognize activities of daily living or events from sensor information. Predefined rules or sequences of rules specify which sensors, sensor values or states (e.g., kettle sensor is on), and, in some cases, time frame and location correspond to a specific activity (e.g., making a cup of tea) or event (e.g., a fall) [12,23,32,36]. A similar approach uses sensor readings, and a predefined ontology that specifies hierarchical relationships between sensors, (household) objects or contexts, and activities or tasks to infer the current activity or task using evidential operations [15] or case-based reasoning [17].

Other approaches to activity recognition use automatically built activity models. These models focus on users’ interaction with objects (e.g., a cup and a kettle) in performing activities (e.g., making a cup of tea), or on users’ presence (over time) in the rooms of the house. They use models of the relevance weight of objects in activities [37], or features extracted from hand-worn sensors that sense magnetic fields emitted by electrical devices to discriminate activities [30]. The former infers the user’s activity from sensor reports indicating her interaction with key objects related to that activity, while the latter computes the activity class of each feature vector extracted from the hand-worn sensors. An alternative approach uses room occupation statistics obtained from motion sensors to build models of Circadian Activity Rhythm based on presence, activity levels and time spent performing individual activities, where rooms are taken to be indicative of certain activities (e.g., bedroom indicates sleeping) [21]. Based on these models, it can recognize activities and identify behavioral anomalies (i.e., changes in behavioral patterns).

3.2.4. Decision making

Many technologies we surveyed use decision making and planning techniques from artificial intelligence to take action based on detected events. This is often achieved by checking detected events against specified rules that set conditions under which to trigger actions, such as notifying caregivers [24,12,22,16,1,17,19,27,29,20].

Other approaches involve triggering alerts based on detected and classified deviations from baseline activity patterns [21]; inferring whether a user is stuck in performing a task and prompting the user according to inferred cognitive difficulties [23]; and filtering user information according to privacy concerns before disseminating it to appropriate parties [35].

3.2.5. Spatiotemporal reasoning

Technologies in this category make use of reasoning techniques that explicitly represent elements of space and/or time and relationships between them. In its most basic form, it uses the user’s location, and predefined spatial information or rules pertaining to spaces (e.g., physical barriers and physical distance, or alert areas) to provide users with relevant information (e.g., the optimal route in a navigation application, or alerts when a user might be at risk) [13,27]. Another approach compares sensed spatial features to the (predefined) spatial characteristics of specific events (e.g., falls) to detect those events
Temporal features can also be used to detect that a specific event has occurred, based on predefined temporal characteristics of the event having occurred (e.g., excessive inactivity in risk areas indicative of a fall) [19]. Specific activities can be detected by reasoning over sensed spatial features (e.g., user location and objects with which the user interacted) using a (predefined) ontology of relationships between objects, contexts and activities [15]. User context (including activity pattern) can be inferred from a combination of sensed spatial and temporal features of events (e.g., user location, position, object of interaction, and time stamps) by software agents using rules specified using concepts from ontologies (e.g., Smart Home, Event and Context ontologies) [32].

Other approaches use motion events detected by sensors throughout the house to gather statistics on activity or presence levels [12,21]. These systems can calculate relative mobility levels for spaces and periods of interest, and automatically build models of “normal” activity and behavioral patterns. These approaches reason about presence and activity levels in various spaces at various times to detect deviations.

3.2.6. Context awareness

Cook and colleagues identify context awareness as a key contributing technology to human interaction with ambient intelligence systems [9]. Context awareness uses devices (e.g., sensors) to infer users’ current activity and the characteristics of their environment to intelligently manage information content and its means of distribution. Our survey revealed a number of approaches to context awareness. Though several technologies make use of some form of context awareness, the focus here is on technologies that use context awareness for human–computer interaction.

Some approaches we encountered focus on providing users with information tailored to the user and her current context. Chang and Wang’s system uses user location (obtained from Bluetooth beacons), personal profiles (including information on physical disabilities and user preferences), and information on environmental barriers (e.g., stairs) to compute a personalized route for the user [13]. The system provides users with directions and instructions at each navigational decision point along the route. The Ambient Annotation System (ANS) uses augmented reality to assist people suffering from Alzheimer’s disease [34]. The system allows caregivers to associate digital tags or notes with objects of interest, by selecting objects in digital images of the user’s home. A user-worn mobile device captures images from the user’s environment from which the system identifies tags. If a tag is detected, the user is notified and an image of the annotated object is displayed with an associated text message.

García-Vázquez and colleagues’ Remind-Me, GUIDE-Me and CARE-Me ambient information systems to remind, guide and motivate elderly users to medicate, use context awareness to intelligently provide users with appropriate assistance [28]. Agents for each of the systems include an Activity-Aware service, which monitors the environment and queries a knowledge base containing a context-aware representational ontology and rules in order to determine the type of assistance the user requires (e.g., appropriate medication reminders, guidance, or motivation). The Remind-Me ambient information system contains an additional Medication-Compliance Aware agent, which monitors medication compliance with personalized medication prescriptions. Hoey and colleagues present a context-sensitive prompting system, which uses sensor observations (caused by a user’s interactions with his or her environment) and behavioral and environmental models of interactions relevant to completing tasks involved in the user’s activities of daily living, which analyzes ongoing activities and prompts the user through the task as needed [23]. Ni and colleagues’ Task Support System they build using this approach detects environment contexts such as humidity, temperature, luminance, and the user’s location to provide adaptive and personalized task assistance, such as environment control (temperature etc.), medication reminders, and call forwarding [17].

Muñoz and colleagues’ ambient assisted living system is based on a multi-agent architecture in which agents analyze data obtained from sensors in the user’s home to infer the user’s context, using Smart Home, Event and Context ontologies [32]. The system aggregates context information from agents that manage each type of context information. Activity patterns are inferred from this information, along with any absence of movement. The system then evaluates the inferred context as safe or unsafe, and triggers an emergency mechanism if needed.

In Ayala and colleagues’ system, agents collect data (from sensors) and monitor this data to determine system context [11]. The system analyzes changes in context and determine if the agent needs to self-adjust (configure or reconfigure its architecture) given the current situation. If needed, the agent self-adjusts according to a plan, which specifies preconditions for its execution and the actions performed in executing the plan.

3.2.7. Graphical user interfaces

Several of the technologies we surveyed use graphical user interfaces (GUIs) for a variety of purposes. One common use is monitoring health-related information. The BehaviorScope Web portal allows users to register different types of data sources (motion sensors, camera-based localization sensors, RFID tags, GPS-enabled mobile devices and simple sensors, such as door sensors and temperature or humidity sensors) [12] to share with other users of the system. The system provides different forms of visualization and statistics, and allows users to define email and SMS notifications and alarms. The system’s Spatiotemporal Filtering Language GUI also allows users to set triggers for alarms and notifications. The Digital Family Portrait informs older adults’ family members of their daily activities, health status, and potential problems, as well as patterns of activities over a time period [1]. Icons for each day visualize the older adult’s average activity level by varying in size. Detailed information on each day can be obtained by touching the day’s icon. Virone’s SAMCAD II GUI displays
plots of presence-based, activity-level-based and activity-based Circadian Activity Rhythms for any day within a selected observation window [21]. It also includes plots of overall behavior deviation (from normal activity patterns), and allows users to plot specific types of alerts. Another panel lets users view behavioral deviations per room or activity. A third panel provides plots of total time spent per activity level per room, or total time spent to perform an activity, per hour of the day over several days.

Other approaches focus on providing users with instructions or reminders, for wayfinding or medication intake, which are tailored to the user's context using information about user location, physical abilities, care needs medication compliance [13,33,14,28]. These are generally presented on handheld devices, as textual instructions and associated images, and video.

3.3. Contexts of use

We examined each of the papers in our selection to identify which stakeholders their technology targeted or would affect, which goals or tasks the technologies were designed to support, and in which environment the technology would be deployed and used. This gave us a list of all of the occurrences of these elements in the papers in our shortlist. We examined the full list of elements of context of use to identify similarities based on which we could create groups of stakeholders, goals, and environments. For example, we found mentions of “older adults”, “elders”, “elderly people”, and “seniors”. We take these terms to refer to the same concept, and labeled the group “elders”.

We identified the following groups of stakeholders.

- elders
- people with a cognitive impairment
- professional caregivers
- family and friends.

We identified the following groups of goals the technologies aimed to support.

- maintain health
- guarantee safety
- control surroundings
- cope with memory loss
- perform activities of daily life.

Finally, we created the following groups of environments in which the solutions we surveyed were deployed.

- home
- outdoors
- residence (i.e., assisted living facility)
- workplace.

Any combination of three elements (one from each group) is a potential context of use. So, there are 80 possible contexts of use. With 37 papers in our shortlist, it did not seem likely that all of these possible contexts would be targeted in the papers we surveyed. To check this, we reexamined which stakeholders, goals and environments each shortlisted paper addresses, and categorized the papers according to the groups presented above. We then counted how many papers addressed each potential context of use.

In deciding which contexts of use (i.e., combinations of stakeholders, goals and environments) to include along the contexts of use dimension of our taxonomy, we opted not to include any contexts that were addressed by fewer than three papers. As a result, we excluded 75 of the contexts of use, and were left with five stakeholder–goal–environment combinations:

- elders – maintain health – home (9 papers)
- elders – guarantee safety – home (7 papers)
- professional caregivers – maintain health – home (5 papers)
- elders – maintain health – outdoors (3 papers)
- elders – control surroundings – home (3 papers).

4. Synthesis: values, contexts of use, and technologies

We examined all possible combinations of a value (physical well-being, social well-being, privacy, freedom, responsibility or safety), a technology (sensing, modeling, activity recognition, spatiotemporal reasoning, decision making, acting, context awareness, natural interfaces, graphical user interfaces) and a context (elders, maintain health, home), a total of 270 combinations. For each combination, we examined which papers addressed that combination. Of the 270 possible combinations, 137 were not addressed by any papers, 66 were addressed by 1 paper each, 36 were addressed by 2 papers, 14 combinations were addressed by 3 papers, 9 combinations were addressed by 4 papers and 8 combinations were addressed by 5 papers.
Social well-being did not occur in any combinations addressed by 3 or more papers. Acting, context awareness, natural interfaces, and graphical user interfaces did not occur in combinations addressed by 3 or more papers. (Elders, Maintain health, Outside) and (Elders, Control surroundings, Home) also did not occur in any combinations addressed by 3 or more papers.

By examining how a value, technology and context is addressed by each paper in each combination, we attempt to identify recurring relationships between values, technologies and contexts. More specifically, for every combination, we examine what is deemed important under the value in this context (e.g., under the value of privacy, one's ability to be secluded in one's home could be the valued state of affairs, or the object of value). We identify how the current context supports or hinders that value. We also identify how the technology in this combination (positively or negatively) changes the context, and how the technology can support or hinder the value.

Many aspects of the combinations we identified that were addressed by three or more papers have elements in common. For example, two combinations address freedom and sensing and two combinations address freedom and modeling, in different contexts. As our focus is on values, we discuss the combinations using values as a starting point.

4.1. Physical well-being

4.1.1. Sensing

Binary sensors on household objects (e.g., water boilers) and infrastructure (e.g., windows) can contribute to elders’ physical well-being by avoiding discomfort of more invasive forms of sensing (e.g., body-worn sensors), and by helping detect health risks and decline, when combined with other technologies (e.g., modeling and activity recognition). Location sensors, in combination with other technologies (e.g., spatiotemporal reasoning), can improve the quality of life of people with dementia and/or cognitive impairments by helping them navigate. User-worn sensors (e.g., accelerometers) can enhance physical well-being, by gathering information that can improve prevention and treatment, such as activity levels. These sensors can also help detect falls, which are a major health risk. However, user-worn sensors can adversely affect physical well-being if they are uncomfortable. Imaging sensors can improve well-being by helping detect falls, without the discomfort of user-worn sensors.

4.1.2. Modeling

Simple modeling in the form of thresholds and rules for raw or aggregated sensor data can contribute to physical well-being by helping detect specific health decline and risks (hence improving treatment and prevention), while avoiding discomfort of activities such as long-term blood pressure monitoring. Thresholds and rules can also contribute to physical well-being by helping elders maintain healthy levels of physical activity, drawing attention to overly high or low levels. Ontologies can improve quality of life by helping individuals cope with some of the difficulties associated with dementia, and by helping detect hazardous situations that could adversely affect individuals’ health. Statistical approaches to (activity) modeling can improve treatment and prevention by providing a model of “normal” activity from which deviations (indicative of health decline) can be detected. Moreover, they avoid the discomfort of more invasive ways of checking individuals’ health status.

4.1.3. Decision making

Decision making technologies can improve physical well-being by notifying caregivers of situations or conditions that require their attention and/or assistance, which supports prevention and timely treatment, reducing injury and harm. It can also improve the quality of life of people with dementia, by prompting them when they get stuck performing tasks. It can also help elders sustain healthy levels of activity by prompting them to be more or less physically active.

4.2. Freedom

4.2.1. Sensing

Sensors on household objects and infrastructure can enhance elders’ independence, allowing them to live in their own home by gathering information (e.g., activity levels) that would normally require caregivers to be present in the elder’s home, that the elder live in a nursing home, or that the elder visit a physician. Such sensors can potentially violate elders’ autonomy if they prevent elders from engaging in certain activities for fear of surveillance. Location sensors can enhance independence of people facing dementia or cognitive impairments who are otherwise physically mobile, by assisting them in navigating, and by reducing the risks of wandering. These sensors can threaten users’ autonomy if they create a chilling effect. User-worn sensors (e.g., accelerometers) can enhance independence by helping to detect risks (e.g., falls), reducing the need for visits from caregivers or placement in a nursing home. They also can help detect signs of health decline, reducing the need for physician visits, which further supports independence. User-worn sensors can violate users’ autonomy if they evoke fear of surveillance, and potentially through the burden (and stigma) of wearing sensors. Imaging sensors enhance independence by helping detect risks such as falls within the home without the burden of wearing sensors. However, the potential of chilling effects, and consequent violation of autonomy, is especially strong with this type of sensor, even if a person is not actually identifiable from the images captured. Sensors that capture vital statistics enhance independence by enabling remote health monitoring, reducing the need for physician visits and hospitalization.
4.2.2. Modeling

Modeling enhances elders’ independence by allowing thresholds and rules to be specified react to certain raw sensor input, which helps involve caregivers in elders’ lives only when necessary and allows elders to remain in their own homes. Ontologies can enhance independence by helping detect adverse events, thus reducing dependence on caregivers. They can also help elders and people faced with dementia or cognitive impairments perform activities of daily living independently by helping detect (in combination with sensors) when the individual is stuck in an activity and making it possible to provide the necessary information (in combination with decision making, activity recognition and/or spatiotemporal reasoning technology) to get them unstuck. These technologies might adversely affect autonomy if elders perceive overreliance on the technology. Statistical approaches to modeling contribute to remote health status monitoring, and reduce physician visits and increase independence, by building a representation of “normal” health, enabling detection of anomalies and deviations indicative of health decline.

4.2.3. Spatiotemporal reasoning

Spatiotemporal reasoning technologies can enhance the independence of people facing dementia and cognitive impairments by helping them navigate—providing them with instructions or directions at appropriate points. Also, it can help determine if they are stuck performing an activity of daily living, and provide them with the appropriate information to complete the activity successfully. The same technology could adversely affect these people’s autonomy if they believe they are overreliant on the technology. Spatiotemporal reasoning can help detect hazardous situations, reducing the need for placement in nursing homes or hospitalization, thereby increasing independence. These techniques also contribute to remote health monitoring, by helping identify health decline from changes in activity patterns.

4.2.4. Decision making

Decision making technologies can support freedom by checking sensed events against pre-specified rules, and contacting caregivers if their assistance is needed (e.g., in cases of emergencies), increasing elders’ independence from caregivers. These technologies can also trigger alerts based on changes in activity patterns that might be indicative of health issues. This can improve treatment, which can prolong elders’ stay in their own home, and increase independence. Prompting technologies (which make use of decision making techniques) help people facing dementia or cognitive impairments maintain independence by assisting them in performing activities of daily life autonomously. Decision making techniques can violate older adults’ autonomy when it offers too much support or raises concerns of overreliance on technology.

4.3. Privacy

4.3.1. Sensing

Sensors on household objects and infrastructure can support privacy because they do not capture identifiable features of a person directly. They can potentially impinge on spatial privacy and activity sensitivity. Also, they can violate privacy in the sense of seclusion if they are always on and there were no location where the individual could choose to be free from monitoring. These sensors can also violate privacy as autonomy, through fear of surveillance elders might experience. Location sensors can impinge on spatial privacy, activity sensitivity (if certain locations are associated with certain activities), privacy as seclusion, and privacy as autonomy in similar ways. User-worn sensors for body movement can hinder privacy by their potential to capture sensitive activities. Privacy as autonomy can be violated through fear of surveillance of body movements. Imaging sensors add additional concerns of being identifiable from captured data. Such concerns might be alleviated by processing images locally, or only using blob images (from which a person cannot be detected), but only if the monitored person understands the technology. All of these types of sensors might raise privacy concerns related to the granularity of the data being captured, the necessity of the capturing, and who the data recipients are. Also, there are potential concerns with regard to control over data collection and dissemination.

4.3.2. Modeling

Activity models have the potential to negatively affect privacy if their use raises concerns about what alerts are triggered and the ability of elders to correct these alerts (or the underlying models). They also potentially adversely affect privacy if they involve sensitive activities (e.g., time spent in the bedroom). An advantage of using is that they can be responsive to very specific data (e.g., acceleration from a fall) and thus avoid using personally identifiable information, except in cases where statistical models of activity are used (which are essentially unique to an individual). Activity models can also raise concerns related to what they capture for what reason.

4.3.3. Activity recognition

Activity recognition techniques have the potential to negatively affect privacy by detecting sensitive activities. They can also raise concerns over what data is generated at what granularity (i.e., what activity is recognized), to whom this is communicated and for what reason. Also, it may raise concerns over the ability to control what activities are recognized and how to correct information generated.
4.3.4. Spatiotemporal reasoning

Spatiotemporal reasoning techniques can negatively affect privacy by combining information (e.g., times of day spent in certain rooms) that could be indicative of sensitive activities. The effects might be reduced by only comparing sensed features to representations of specific events (e.g., a long time spent on the floor could be an indication of a fall). Other privacy concerns can include granularity of the spatiotemporal reasoning.

4.3.5. Decision making

Decision making techniques, in the form of notifications to caregivers and other interested parties, can negatively affect privacy by raising concerns about what data is communicated to whom, with what granularity or level of detail.

4.4. Safety

4.4.1. Sensing

Sensors on household objects and infrastructure can enhance safety by helping make unattended events and other potentially hazardous situations detectable. Location sensors can protect safety by preventing problems with wayfinding and wandering, helping protect the safety of wandering-prone individuals (e.g., people facing dementia) by tracking their whereabouts. User-worn motion sensors can help detect falls, as can imaging sensors. Sensors for vital signs can help detect health issues.

4.4.2. Modeling

Modeling techniques further improve safety by allowing systems to be responsive to certain sensed events (e.g., falls or excessive inactivity). Ontologies can help by enabling systems to assess whether a situation, environment or context is safe or unsafe, and detect unattended events. Statistical models can enhance safety by enabling early detection of health decline.

4.4.3. Activity recognition

Activity recognition can use models to detect hazardous events, unsafe contexts and health decline in a timely manner.

4.4.4. Spatiotemporal reasoning

Spatiotemporal reasoning techniques enhance safety by helping people facing dementia navigate, and by detecting when they are wandering (which can be hazardous). It can also help detect potentially hazardous situations (e.g., a stove left unattended, or front door left open). Spatiotemporal reasoning can also help identify deviations in activity patterns that might indicate health issues or health decline. These techniques can also be used to detect specific hazardous events (e.g., a person has fallen and has subsequently been inactive for an excessive period of time).

4.4.5. Decision making

Decision making techniques enhance the safety of older adults by notifying caregivers in emergencies, getting elders the assistance or treatment they need on time, hence reducing harm.

5. Conclusion

Pervasive computing has the potential to address many of the problems societies with aging populations face, by making computers available anywhere at any time (or even everywhere and all the time). As computing weaves itself into our everyday lives, the opportunities for it to affect our lives positively and negatively are more numerous than ever before. Pervasive computing’s envisioned deep intertwining with our lives makes human values a fundamental consideration for this field.

Designers working in pervasive computing are faced with a wide range of issues to take into account. This increasingly includes issues such as indirect stakeholders, contexts and values, which might not be concepts designers are used to dealing with extensively. Designers are forced to come up with ways of dealing with these unfamiliar concepts. Unfortunately, there are few ways of systematically identifying these issues, and there is little guidance on dealing with these issues in design. Where these issues are successfully addressed in design, the resulting design knowledge is often lost for lack of a systematic way to capture and communicate it. As a result, examples of best practice might not be readily available.

In this paper, we used concepts from VSD to identify values, technologies and contexts of use in this domain. We developed a taxonomy in which we categorized the identified elements. This taxonomy served as a starting point to analyze the relationships between values, technologies and contexts of use in pervasive computing for health care.

We argue that understanding these relationships can help designers better consider the values their technologies affect. We believe this will help designers weave computing technologies into our everyday lives in a way that is sensitive to the needs and values of the people living those lives, and to the contexts in which they are lived.

Our focus in this paper was on explicitly supported values, or at least values that were explicitly mentioned. Explicitly supported values are not the only values to consider. Stakeholders' values and (unarticulated) designers' values should also...
be considered, in order to get a more complete understanding of which values the technology might (inadvertently) support, hinder, violate or otherwise affect and take this into consideration in design. Future work should develop ways of uncovering these other values as part of analysis.

References