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The indoor environment and the integrated design of homes for older people with dementia

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Abstract There are currently about 6 million -mainly older- people with dementia in the European Union. With ageing, a number of sensory changes occur. Dementia syndrome exacerbates the effects of these sensory changes and alters perception of stimuli. People with dementia have an altered sensitivity for indoor environmental conditions, which can induce problematic behaviour with burdensome symptoms to both the person with dementia and the family carer. This paper, based on literature review, provides an overview of the indoor environmental parameters, as well as the integrated design and implementation of relevant building systems. The overview is presented in relation to the intrinsic ageing of senses, the responses of older people with dementia and the impact on other relevant stakeholders through the combined use of the International Classification of Functioning, Disability and Health, and the Model of Integrated Building Design. Results are presented as indicators of the basic value, functional value and economic value, as well as a synthesis of building-related solutions. Results can help designers and building services engineers to create optimal environmental conditions inside the living environments for people with dementia, and can be used to raise awareness among health care professionals about of the influence of the indoor environment on behaviour of the person with dementia.

Keywords Indoor environment, dementia, behaviour, older adults, senses, light, noise, sound, indoor air quality, family care, integrated building, technology

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1. Introduction

Senses are the primary interface with our environment. With biological ageing, a number of sensory changes occur as a result of the intrinsic ageing process in sensory organs and their association with the nervous system [1]. Over time, the accumulated atrophy of sensory receptors substantially reduces the quality of environmental impressions [1]. The age-related changes to our senses can be an even greater problem when coping with symptoms of dementia syndrome. Dementia is the loss of cognitive function of sufficient severity to interfere with social or occupational functioning. There are about 100 known causes of dementia syndrome, of which Alzheimer's disease (AD) has the highest incidence. Contrary to popular belief, loss of memory is not the only deficit in dementia. Impairment in activities of daily life and abnormal behaviour are common symptoms [1]. The intensity of symptoms may differ over time [2]. Many people with dementia have an altered sensitivity to environmental conditions, which can result in behavioural problems [3]. These form a serious burden for family carers and and are one of the reasons for long-term institutionalisation. The altered sensitivity seems to stems from the reduction of the individual's ability to understand the implications of sensory experiences [3]. This is aggravated by the age-related deterioration in sensory acuity that affects vision and hearing steadily over the years [4].

Dementia sets special demands to the design of housing facilities and the home's physical indoor environment and technology [5-8]. The physical indoor environment comprises the thermal environment, the indoor air quality (IAQ), lighting, and the acoustic environment. In a broader sense, it constitutes all that the individual hears, sees, feels, tastes, and smells [9], and all together, these parameters have an impact on whether someone feels comfortable. Comfort is a state of mind, which expresses satisfaction with the total indoor environment or one of its parameters. In case of persons with dementia, this definition is difficult to apply as these persons have an unknown 'state of mind', and as these persons might lack the ability to express themselves reliably other than by expressing (dis)satisfaction via certain behaviours [7]. Tilly and Reed [10] state that in case of behavioural problems, environmental techniques should be among the first strategies used as a treatment, rather than beginning with pharmacologic interventions. The home's physical indoor environment is thus not only the key factor in providing comfort, but might even be a nonpharmacologic factor in managing problem behaviour in dementia. It may thus be a yet largely unexplored factor in reducing carer burden. According to Aminoff [11], poor indoor environmental quality may have a role in the suffering of people with dementia. Also, Florence Nightingale [12, p. 5] was well aware of the influence of the indoor environment on the progress of disease and recovery, and her messages do not go unnoticed [13].

> "*In watching diseases […] in private houses […], the […] symptoms or the sufferings generally considered to be inevitable and incident to the disease are very often not symptoms of the disease at all, but of something quite different – of the want of fresh air, or of light, or of warmth, or of quiet, or of cleanliness, of each or of all of there.*"

Van Hoof et al. [7] already concluded that nursing literature in general provides clear indications in the form of anecdotal evidence that people with dementia are generally very sensitive to (changes in) indoor environmental conditions and that their perception differs from healthy subjects. Unfortunately, such studies have not yet resulted in the development of practical guidelines for the building sector how to create optimal indoor environments for people with dementia, and protocols for care professionals for signalling building-related behavioural and other health problems. The design and maintenance of the indoor climate is the domain of various professions in the field of construction and technology, not nursing in particular. Good design calls for an integrated approach. The integrated design of buildings in itself is a complex process; involving numerous stakeholders, disciplines and building systems, which aims at creating a range of stakeholder-related values or benefits [14]. When considering housing for older adults with dementia, it is this specific group of people that is most affected when the actual needs are not considered in the design process and if a building cannot deliver its full potential of values to all users. Therefore, the goal of this paper is to present a literature review of the indoor environment, in particular (i) air and odours, (ii) light and lighting, and (iii) the acoustical environment for older people with dementia in relation to the ageing of senses and dementia. The review focuses on the building-related basic, functional and economic values for the relevant stakeholders and provides a synthesis of building-related solutions. Although the perception of the thermal environment is affected by biological ageing and dementia syndrome [7,15-18], the thermal environment is not within the scope of this paper, as van Hoof et al. [7] presented a complementary paper on thermal comfort and dementia.

2. Methodology

2.1. Literature study

The literature study included both peer-reviewed articles and books on (i) ageing senses and perception of indoor environmental parameters by older adults, and (ii) housing for older people with dementia, (iii) behavioural problems among people with dementia in relation to indoor environmental parameters, and (iv) design guidelines for technology for people with dementia and the installers of such technology. The search included all relevant sources without a limitation to the age (up to October 2009). As persons with dementia are living in a continuum of housing [6], including institutional types of housing, such as nursing homes, small-scale group settings, and special care units (SCUs), the literature covers the whole range of living environments. Although the main focus of this paper is on the home environment, literature concerning institutional settings provide important information that are relevant to the own home, and are therefore included in this study. Quotes appearing in qualitative studies, which summarise the essence of a person’s subjective experience, are included in the literature review only for further illustration of certain topics.
The literature search was complicated by the large differences in the way problems are conceptualised between nursing/occupational therapy, and the technological sciences. For instance, a different meaning is given to the term physical environment: (i) the indoor environment as a whole, or (ii) the whole of the thermal, visual, and acoustical environment and IAQ. There are also significant differences in the way professionals from both fields approach and perceive dementia syndrome and related health problems and challenges, as well as in the level of conceptual thinking when dealing with these challenges.

2.2. Framework for the analysis

The data of the abovementioned literature study are structured and presented using a novel combination of two existing frameworks: (i) the International Classification of Functioning, Disability and Health (ICF) [19] with its basis in health sciences, and (ii) the Model of Integrated Building Design (MIBD) by Rutten [14] that has its origins in building sciences. This combined model was first presented in van Hoof et al. [7]. Such a combined framework is needed as this study tries to bring together demand and supply, namely the needs of the stakeholders and the solutions offered in the field of construction and technology.

2.2.1. International Classification of Functioning, Disability and Health

Within the World Health Organization's ICF [19], health problems are described as well as limitations and/or restrictions that result from diseases and disorders (Figure 1). The overall aim of this classification is to provide a unified and standard language and framework for the description of health and health-related states. ICF has two parts, each with two components: Part 1: Functioning and Disability: a.) body functions and structures, b.) activities and participation, and Part 2: Contextual Factors: c.) environmental factors and d.) personal factors. Each component can be expressed in both positive and negative terms.

Impairments are problems in body function (physiological functions of body systems) or structure (anatomical parts of the body) such as a significant deviation or loss. Within ICF, the severity of a disorder is described, which provides insight into treatments, medication or adjustments of activities, as well as participation or environmental factors. Activity is the execution of a task or action by an individual. Activity limitations are difficulties an individual may have in executing activities, such as domestic work and personal care. Participation is involvement in a life situation. Participation restrictions are problems an individual may experience in involvement in life situations. Within the ICF, the built or living environment can be seen as an environmental or contextual factor that influences people at the impairment level, and helps people to overcome limitations and restrictions posed by declining physical fitness and cognition. The indoor environment as treated in this paper is characterised by the ICF factors e155 (technical aspects of a private building), e240 (light), e250 (sound), e260 (air quality). These factors may hinder or support the activities or participation of a person with dementia. To analyse the hindrance or support posed by any of these factors, the MIBD is used.

INSERT Figure 1 HERE

2.2.2. Model of Integrated Building Design

Rutten [14] presented the MIBD (Figure 1), which provides an overview of sub-aspects of the design process of a building and the desired building performance levels. In this model, a building derives its total value based on the quality of its relationship with the human environment or how well it performs at all of the various human perspectives from which it is viewed, i.e., it fulfils needs. A performance specification describes performance goals for each human-building relationship. Rutten [14] suggests that by considering the combined performance of top-level requirements (the six so-called value-drivers that represent various stakeholders), one can determine a building's total value. This total value is realised through the integrated functioning of a number of building systems on the demand side via a system engineering approach. Such an approach implies that an overview of dominant building systems is made, which in turn are distinguished in several levels in such a way that functional integration is achieved with consideration of the various disciplines involved in the building proces. The MIBD tries to achieve value integration, in which all values and stakeholders are integrated in order to achieve functional integration.

Within the MIBD, six values and domains are distinguished, namely the basic, functional, local, ecological, strategic, and economical values. In this study, the scope of MIBD is extended to the analysis of living environments. The ICF has a specific connection to three of the values of the MIBD when looking at housing facilities for older adults (which is explained in the following section), and therefore, emphasis will be on the basic value, functional value and economic value.

- The basic value is determined from a building's relationship with individual occupants and their sense of psychological and physical well-being. The person with dementia is the most important stakeholder in this section. The family carer is the one who takes care of the person with dementia, and therefore their needs are incorporated as well.
- The functional value is concerned with how activities and processes (including facilitating care) taking place inside the building are supported. In short, how facilitatory and supportive is a living environment to the activities that take place inside, and the person with dementia and the family carer? The person with dementia should be able to lead the life he/she wants to lead -within the constraints posed by dementia- with the help of a living environment that facilitates for the deficits seen in dementia.
- The economic value is based on the relationship with people concerned with the ownership and marketing of the building. When the economic value is maximised in relation to the needs of people with dementia and their partners, a home should facilitate ageing-in-place and the provision of care, and should minimise the burden of family and professional care. At the same time, a well-tailored home increases in value on the real estate market.

As many aspects of the functional value and economic value are described by van Hoof et al. [7], the main focus in this paper is on the basic value.

The building itself is made up of several systems or components, the six S's: stuff, space-plan, services, skin, structure, and site [20]. These components can be further divided into sub-system components. Each system has a specific set of functions (which can be seen as solutions) that contribute to the optimisation of a certain value. In this paper, various sub-systems such as the floor (structure), façade system and curtains (skin), interior design, floor covering and finishings (stuff), and technological systems and controls (services) are discussed in relation to the needs of relevant stakeholders.

2.2.3. Combined model

The ultimate goal of this study is the creation of living environments which optimally account for the actual situation of a person with dementia and his/her family carer. In order to retrieve how and to what extent integrated building design can contribute to improving living conditions of people with dementia, a framework for further analysis is necessary. Such a framework should allow for the identification of needs of persons with dementia and other relevant stakeholders, and subsequently should help to identify which types of design solution are present in relation to a specific need. This should then be followed by looking at the fit or gap between the demand and supply (need and solution). Within the scientific domains of construction and health care, such a framework for analysis that matches the mindsets of both scientific domains did not exist. This led to the combined use of ICF and MIBD [7]. Following from the purpose of this study, the connection between ICF and MIBD is as follows. ICF

characterises external factors, which may hinder or support activities or participation of a person with a (chronic) disease or impairment. The MIBD has the tools to analyse which external (environmental) factor causes hinder or support for a person with a chronic disease/impairment.
With the basic value of the MIBD the individual needs of the stakeholders as classified in ICF terms can be described. Also, hinder or support from external factors on the level of the individuel can be identified. The functional value of the MIBD deals with answers and solutions to the needs of the organisation (in order to support individuals). This value allows for the identification of hinder or support on the level of an organisation. The economic value of the MIBD deals with the fit between demand and supply (cost-benefit analysis), and in this way hinder or support for individuals on a macroeconomic level is described. From a practical point of view, the novel approach allows for a problem analysis from the viewpoint of the care recipient (i.e., person with dementia), which forms the basis of ICF, and to integrate the building process in such a way that it leads to more fitting and appropriate outcomes for persons with dementia and other stakeholders. The combined model puts the human being (occupant or stakeholder) and his/her needs in the centre, not the building itself.

3. Basic value

This section deals with the domain of the basic value, which concerns the needs of the main stakeholder; the individual person with dementia, and in line with this stakeholder, the family carer, in relation to the indoor environment. In this paper, focus is on those body functions that diminish due to biological ageing or dementia syndrome, namely a person's sensory organs and their association with the human brain, and perception. This analysis is followed by three more in-depth overviews of (i) changes to the olfactory sense in relation to indoor air, (ii) changes to vision and the eye in relation to the visual environment, and (iii) changes to hearing in relation to sounds and the acoustical environment. These changes are related to ageing and to the incidence of dementia.

3.1. Health condition and body functions: ageing, dementia, senses and perception

A person's cognitive functioning can be seen as a path along which information is processed through five types of functioning or phases: sensory phase, perception and comprehension phase, executive phase, expressive phase, and motoric phase [9]. The age-related sensory changes, involving sensory receptors in the eyes, ears, nose, buccal cavity, and peripheral afferent nerves [1], frequently affect the sensory phase [9]. Apart from the sensory changes, incorrect or malfunctioning visual aids and hearing aids may have a negative effect too [9]. Sensory losses or impairments, together with cognitive deficits, make it difficult for the individual to interpret and understand the environment (perception and comprehension phase) [1,9,21,22]. Perception arises from the integration of sensory signals into percepts that give meaning to raw data, which depends both on sensations and on experience [1]. Dementia is characterised by an impaired identification of incoming stimuli (perceptual deficits), resulting in distorted perceptions [23]. These can lead to illusions or delusions, which in turn elicit paranoid or aggressive response. Perceptual deficits are present even at early stages of dementia and progressively worsen [23]. Some people with dementia have hallucinations, which seem real to the person experiencing them and can be frightening to relatives [2]. According to Turner [24], a person with dementia may spend hours fussing at a shadow 'that has come to life'. Misinterpretations of inappropriate lighting, shadows, and even distorting of floors, walls and furniture are reported [25], which can cause people with dementia to fall. Moreover, many people with dementia have short attention spans and are easily distracted [23]. People with dementia may become increasingly reactive to their environment rather than acting upon it [9]. Pynoos et al. [26] state that persons with AD can be affected by their environment, particularly in the early and middle stages of the disease. These people may be more sensitive to environmental frustrations, including glare and noise, which negatively affect behaviour. Senses can be both overloaded and understimulated leading to a number of problem behaviours or to sensory deprivation [2,27]. Sensory overload is most often caused by abrupt, unexpected environmental changes. For instance, an abundance of stimuli can cause agitation and anxiety for people with dementia, which further heightens disorientation and confusion [28].

The abovementioned findings can be illustrated by a number of practice-based studies. Cohen-Mansfield and Werner [29] studied associations between behaviours and environmental characteristics in nursing home facilities by observing 24 residents for a period of 9.5 months. They found that (i) pacing increased under normal light conditions and normal temperature during daytime, that (ii) noise levels were associated with a decrease in picking at things and strange movements, and that (iii) requesting for attention was associated with hot temperatures during daytime. Cohen-Mansfield and Werner [29] conclude that even though there have been suggestions that persons with dementia manifest agitation as a result of overstimulation in the nursing home, and need a low stimulation and a quiet environment to reduce their agitation, their own results do not support that hypothesis. They state that boredom and lack of activity seemed the true source of agitation. Zeisel et al. [30] measured associations between environmental design features of special care units and the incidence of problem behaviours. In facilities where sensory input was more understandable and input was more controlled, residents tended to be less verbally aggressive. According to Lucero [31], exit-seeking wandering behaviour in middle-stage dementia residents may be a reaction to discomfort or overstimulation. Price et al. [32] also suggest that wandering behaviour may even be a way to escape discomfort. In a study in two dementia clinics, Victoroff et al. [33] found that particularly agitation is associated with burden and depression among family carers, whereas no significant association between delusions and hallucinations was reported. The reduction of environmental stressors can help to minimise agitation.

INSERT TABLE 1 HERE

Since people with dementia respond on a sensory level, rather than on an intellectual level [34], and given some of the cognitive and behavioural problems, extra attention should be paid to the indoor environment in relation to comfort and behaviour. It is, however, important to stress that cognitive impairment is not caused by environmental design, but problem behaviours (Table 1) may be exacerbated by inappropriate housing facilities [23]. Cohen and Weisman [21] stated that one of the design goals for dementia should be to provide opportunities for stimulation and change, carefully regulating sensory stimulation to avoid either deprivation or overload. Bowlby Sifton [38] calls for sensory stimulation without stress; the environment of institutional settings should feel, smell, and sound like home. According to Zeisel [39], an entire environment should be designed so what people see, hear, touch and smell all give them the same, consistent, information about the environment in a holistic manner to understand the environment around us. Healthy persons balance the good features against the bad to reach their overall assessment of the indoor environment [40], and not all aspects are equally important in this subjective averaging process. It is likely that this finding applies to persons with dementia too.

3.2. Air and odours

Indoor air quality deals with the content of indoor air that could affect health and comfort of building occupants [41]. IAQ is related to building materials, ventilation, and activities carried out in the home. Our awareness of the presence of airborne chemicals in our environment relies on two sensory systems: olfaction and chemesthesis or the common chemical sense [42]. The first sense gives rise to the perception of odours, and the second gives rise to the perception of pungent sensations [42]. Olfaction is closely linked to the sense of taste. These senses intertwine to provide links to the environment, and allow appreciation of good tastes and smells [1].

INSERT TABLE 2 HERE

3.2.1. Ageing-related changes in olfaction

Age-related losses of smell and fine taste normally begin after the age of sixty (Table 2) [1]. Age-related sensory changes to smell and taste include a decrease in the number of olfactory cells, and a possible decrease in size and number of taste buds. These changes may lead to decreased appetite and poor nutrition, as well as a decreased protection from noxious odours and the intake of tainted food.

In the human forebrain, the olfactory bulb is a structure involved in olfaction, the perception of odours. Changes in smell are attributed to loss of cells in this bulb, and a decrease in the number of sensory cells in the nasal lining [1]. In addition, a history of upper respiratory infections, exposure to tobacco smoke and other toxic agents negatively influence olfactory function, as well as changing levels of hormones. There is strong evidence that smell perception declines markedly with age [1].

3.2.2. Dementia-related changes in olfaction

The olfactory sense in older adults with dementia is affected by ageing and specific pathologies. This directly influences the perception of indoor air quality and smells, and poses restrictions to the way IAQ is maintained. Moreover, the specific lifestyle of older people with dementia influences the IAQ.

Olfactory dysfunction is a common feature in several neurodegenerative disorders, including AD, Down’s syndrome, and Parkinson’s disease. Neurofibrillary tangles and senile plaques in the olfactory system have been reported in AD [44]. Researchers even purport that the inability to recognise smells, combined with the lack of awareness that olfactory sense is impaired, may be useful as a predictor for AD [1].

There is other research that suggests the impairment is primarily in odour identification, not detection [45]. Diesfeldt [46] mention that in some people with AD the ability to smell decreases before memory disturbances become noticeable. Only in AD, the elementary odour detection is lowered, i.e., differences between odours. All types of dementia affect ‘meaningful odour recognition’, for instance, that a certain odour smells of fruit. In people with AD, this association problem was related to any particular odour. People with semantic dementia had difficulty with all associative

tasks, even if these tasks were not related to any particular odour. Persons with this type of dementia do no longer recognise the meaning of words and objects, and may perceive inedibles as edible.
The olfactory bulb is linked to the thalamus-cortical region and the limbic system via the olfactory tract [47], parts of the brain affected by AD. The limbic system affects behavioural reactions associated with smell, whereas the thalamus-cortical region is responsible for the conscious perception and fine discrimination of smell [47]. The sense of smell often seems to have a strong hold on human emotions, because of the connection to the limbic system, which is associated with emotion and memory processing [34,47].

3.3. Light and lighting

Of all indoor environmental factors in the homes of older adults with dementia, lighting is the most important and promising in terms of improving health and quality of life. The best-known benefits of lighting are visual, i.e., being able to see, and prevention of falls [48]. Falls in dementia result from cognitive and behavioural disorders, visuospatial impairment and motor apraxia, gait and balance disturbances, malnutrition, adverse effects of medication and fear of falling [48,49]. Moreover, lighting plays an essential role in managing numerous biological and psychological processes in the human body, including disturbed sleep patterns.

3.3.1. Ageing-related changes in vision

Ageing negatively affects vision. In general, the performance of the human eye deteriorates at early age. Many people aged 45 and over wear glasses to compensate for impaired vision due to presbyopia, the significant loss of focussing power. Older people are known to have vision impairments stemming from the normal ageing process, which include (i) an impaired ability to adapt to changes in light levels, (ii) extreme sensitivity to glare, (iii) reduced visual acuity, (iv) restricted field of vision and depth perception, (v) reduced contrast sensitivity, and (vi) restricted colour recognition [34]. Changes in vision do not happen overnight, and depend on the progress of age. After the age of 50, glare and low levels of light become increasingly problematic. People require more contrast for proper vision and have difficulty perceiving patterns. After the age of 70, fine details become harder to see, and colour and depth perception may be affected [34,50]. An overview of age-related changes to vision is given in Table 2. Apart from the influence of ageing, there are pathological changes leading to low vision and eventual blindness, such as cataract, macular degeneration, glaucoma, and diabetic retinopathy [50,51].
Impaired vision does not only influence independence, but also has severe implications to social contacts, which in term can lead to loneliness. Research by Aarts and Westerlaken [52] in the Netherlands has shown that light levels, even during daytime, are too low to allow for proper vision and biological effects, even though the semi-independently living older persons were satisfied with their lighting conditions. A similar study was carried out among 40 community-dwelling older people in New York City by Bakker et al. [53]. Even though nearly all of them had inadequate light levels, subjects rated their lighting conditions as adequate.

3.3.2. Dementia-related changes in vision

Dementia has a severe impact on the human visual system, and the effects of biological ageing often aggravate the visual dysfunctions stemming from dementia. Persons with AD frequently show a number of visual dysfunctions, even in the early stages of the disease [54]. These dysfunctions include impaired spatial contrast sensitivity, motion discrimination, and colour vision, as well as blurred vision. Altered visual function may even be present if people with dementia have normal visual acuity and have no ocular diseases [54]. Another dysfunction is diminished contrast sensitivity, which may exacerbate the effects of other cognitive losses, and increase confusion and social isolation [50]. Impaired visual acuity may be associated with visual hallucinations [55]. According to Mendez et al. [56], persons with AD have disturbed interpretation of monocular as well as binocular depth cues, which contributes to visuospatial deficits. The impairment is largely attributed to disturbances in local stereopsis and in the interpretation of depth from perspective, independent of other visuospatial functions.

3.3.3. Ageing and non-visual effects of light

Moreover, light plays a role in regulating important biochemical processes, immunologic mechanisms, and neuroendocrine control (for instance, melatonin and cortisol), via the skin and via the eye [43,57]. Light exposure is the most important stimulus for synchronising the biological clock [58], suppressing pineal melatonin production [59], elevating core body temperature [60], and enhancing alertness [60,61]. The circadian system, which is orchestrated by the hypothalamic suprachiasmatic nuclei (SCN), influences virtually all tissue in the human body.

INSERT FIGURE 2 HERE

In the eye, light activates intrinsically photosensitive retinal ganglion cells [62], which discharge nerve impulses that are transmitted directly to the SCN [63] (Figure 2), and together with the photoreceptors for scotopic and photopic vision participate in mammalian circadian phototransduction. These ganglion cells [65] have a different action spectrum from rods and cones, and show short-wavelength sensitivity [66]. In older adults, the orchestration by the SCN requires ocular light levels that are significantly higher than those required for proper vision are. An additional problem is formed by the ageing of the eye that leads to opacification and yellowing of the vitreous and the lens, limiting the amount of bluish light reaching the retinal ganglion cells [43]. This can be as much as a 50% reduction in 60-year olds compared to 20-year olds. Many older adults are not exposed to high enough illuminance levels, due to decreased lens transmittance, poorly-lit homes (up to 400 lx), and the short periods of time spent outdoors [52,67].
Light also has an effect on the pineal gland that secretes melatonin. The secretion of this hormone depends on the availability of (day) light. Sufficient amounts of light (particularly the lower wavelength part of the spectrum) [66,68], suppresses melatonin secretion, while during darkness, melatonin secretion is stimulated. This melatonin secretion is related to the exposure to light during daytime [69,70]. A high exposure to light during daytime, increases the nocturnal secretion of melatonin [71-73], and makes older adults less sensitive for light exposure at night, for instance, when going to the toilet. Being exposed to light at night may reduce the level of melatonin and therefore reduce the time it takes to fall asleep. Exposure to light during daytime should in turn positively impact sleep, both quantitatively and qualitatively.
Sufficient daily sleep is indispensable for restoration of body and brain. A lack of good sleep slows reaction time, decreases alertness and attention, and affects mood and performance in a negative way [74]. About 40 to 79% of older people suffer from chronic sleeping problems and insomnia [52]. Changes in the timing of many

circadian rhythms in the body are related to that of sleep. The lessening of the amplitude of the 24-hour rhythm in body temperature means that the lowering of body temperature in the evening is less pronounced. This lessening can be a random combination of a decreased functioning of the body clock, decreased physical activity during daytime, and a decreased nocturnal secretion of melatonin [64].

3.3.4. Dementia and non-visual effects of light

In people with AD, the SCN are affected by the general atrophy of the brain, leading to nocturnal restlessness due to a disturbed sleep-wake rhythm, and wandering [64,75]. The timing of the sleep-wake cycle can show a far wider variation; times of sleep and activity can vary substantially from day to day, or can be temporarily inverted [64], which has great implications to both the person with dementia as its family carer. Restlessness and wandering form a high burden for caregivers, and are among the main reasons for institutionalisation [67,76,77]. Marshall [78] stated that lighting technology deserves more attention as a means to help with managing problem behaviour. Hopkins et al. [79] have suggested a relation between illuminance levels and this type of behaviour before, and today light therapy is used as a treatment to improve sleep in people experiencing sundowning behaviour [80].

It is hypothesised that high intensity lighting, with illuminance levels of well over 1,000 lx, may play a role in the management of dementia. Bright light treatment with the use of light boxes is applied to entrain the biological clock, to modify behavioural symptoms, and improve cognitive functions, by exposing people with dementia to high levels of light (for instance, [81-84]), requiring supervision to make them follow the total protocol and may cause a bias in the outcomes of the therapy. The results of bright light therapy on managing sleep, behavioural, mood, and cognitive disturbances show preliminary positive signs, but there is a lack of adequate evidence obtained via randomised controlled trials to allow for a widespread implementation in the field [85-87].

Another approach that is gaining popularity, both from a research, ethical and practical point of view, is to increase the general illuminance level in rooms where people with dementia spend their days to a high level [50]. Studies by Rheaume et al. [88], van Someren et al. [89], Riemersma-van der Lek et al. [90], and van Hoof et al. [91,92], that exposed institutionalised people with dementia to ambient bright light through ceiling-mounted luminaires showed short-term and long-term effects as lessened nocturnal unrest, a more stable sleep-wake cycle, possible improvement to restless and agitated behaviour as well as sleep, increased amplitude of the circadian body temperature cycle, and a lessening of cognitive decline. A cluster-unit crossover intervention trial by Sloane et al. [93] on the effects of high-intensity light found that nighttime sleep of older adults with dementia improved when exposed to morning and all-day light, with the increase most prominent in participants with severe or very severe dementia. Hickman et al. [94] studied the effects on depressive symptoms in the same setting as Sloane et al. [93], persons with dementia. Their findings did not support the use of ambient bright light therapy as a treatment for depressive symptoms. To date, it is unknown how long effects of bright light last and how to predict which persons respond positively to light treatment [76]. More relevant is how to implement these preliminary results in the home situation, for instance, when trying to improve vision.

3.4. Noise and room acoustics

The sense of hearing is related to the perception of sounds. When considering noise and room acoustics, the most important parameters are sound pressure level and reverberation time. These parameters are crucial in creating supportive environments, both in terms of supporting hearing, as well as reducing negative effects associated with sounds and noise.

3.4.1. Ageing-related changes in hearing

In addition to sight, one of the first senses to be affected by age is hearing, and this begins to occur by the age of 40 (Table 2). High frequency pitches are the first to become less audible, with a lesser sensitivity to lower frequency pitches [1]. The ability to understand normal conversation is usually not disturbed at first, but when combined with the presence of background noise comprehension may be affected. In the United States, about one third of the community-dwelling older people are hearing impaired [1]. A laboratory study from Japan [95] involving 20 younger and 20 older subjects using various speech tests showed that speech recognition (intelligibility) scores of the older listeners were 25% lower than those of young adults for any kind of speech test. The effect of this difference is equal to the 5 dB increase of ambient noise.

3.4.2. Dementia-related changes in hearing

Apart from the effects of biological ageing, there are no reported effects of dementia on hearing, apart from the occurrence of acoustical hallucinations (Table 1). Most older people lose hearing ability, and can compensate by a combination of lip reading, increased attention, and extrapolation from the parts of sentences they can hear [96]. For a person with dementia, this compensation becomes problematic, and that is why it is important to minimise meaningless background noise [97]. It can be hard to sort meaningless cues and stimuli from those that are meaningful or important [97]. Hearing aids may magnify background noise. People with dementia often cannot learn to compensate for this [2] or perceive the sounds as offensive [34]. Burton and Torrington [28] mention that sudden loud noises often frighten people with dementia. Hearing aids are crucial for people with hearing loss, since they contribute to communication abilities that are already negatively affected by dementia. They may prevent a state of sensory deprivation [98].

In institutional settings, noise has been associated with poor sleep, reduced ability to perform tasks, distraction from completing a task, agitation and fear [3,11,99]. In a qualitative study by Hyde [96] involving Alzheimer's facilities staff, one unit director advised the follwing in relation to unnecessary auditory stimulation: "*Listen to the noise level. The phone ringing, the intercom, it's a necessary evil, but they think God is talking to them.*" It is unclear whether this apparent confusion is a source of fear or other negative feelings, or reassurance, or a combination of both. Apart from the confusion, sounds may cause a wide range of negative side effects. Often noise is an accepted part of the routine of people with dementia [11].

4. Functional value

The domain of the functional value deals with the needs of the organisation. Within this domain, production support and reliability play a role as performance indicators. This can be both the impact on care giving processes of the family or professionals, as well as the production processes within the domains of care, housing and technology. Based on the needs of the organisation and those of their clients, raising the level of awareness of the stakeholders of the impact the indoor environment may have on persons with dementia is of the utmost importance. The requirements within the domain of the functional value have a significant overlap with those stated in relation to thermal comfort [7], in particular the aspects related to the professionals from the technological domain. Therefore, only some of the highlights are described.

4.1. Raising awareness

Relevant organisations, family and professional carers need to be made aware of the consequences the indoor environment can have on the behaviour and functioning of person with dementia care processes. Also, increased awareness should be raised on how the good design and implementation of relevant building services and systems can lead to more efficiency in dementia care processes. Even though dementia can significantly change how people interpret what they sense, the extent is highly individual and in constant flux, depending on neuropathological changes, sensory loss, time of day, medication management, and the social and physical environment [100]. All relevant actors should be aware of this phenomenon too.

Raising awareness is also needed in terms of design and the operation of technology. The sensitivity of people with dementia stretches beyond sensitivity for actual physical conditions, for instance, to operational factors. Invasive technology, like lights switching on seemingly spontaneous, automated movement of curtains, and noisy ventilation systems can cause distress. Systems installed with the best of intentions, which are unfamiliar, are not understood by people with dementia and should therefore be left out of a dwelling. The complexity of technology can have an unwanted disabling effect on the person with dementia [101]. Bakker [100] states that at times, the loss of function of residents with dementia is incorrectly blamed on dementia, when inappropriate design is at the basis. This is the point when specialised knowledge from designers and installers is wanted.

Tilly and Reed [102] provide an example of wrong design, applied to alarm systems used to alert the staff when a wandering resident is attempting to leave the facility. One should choose the system that is the least intrusive and burdensome. For some, alarm systems are a burden and may even lead to agitated behaviour, as evidenced by the resident’s protests or attempts to remove it. Furthermore, alarms that are audible to the resident may discourage any movement. The implementation of a seemingly good solution may turn out detrimental.

4.2. Standards and guidelines

Current standards and guidelines for indoor environmental quality should be applied with caution when working with persons with dementia. Current standards and guidelines do not provide sufficient data on this group of people, and it seems that the demands set to the indoor environment should be a lot stricter. In general, the quality of the indoor environment may be expressed as the extent to which human requirements that have great interindividual variety are met. Some people are known to be rather sensitive to an environmental parameter and are difficult to satisfy [103], and this seems to be particularly true for people with dementia. Other relevant building regulations tend to be primarily written for the needs older people with a physical impairment, rather than for people with mental of cognitive impairments. When recommendations are made for people with dementia, even these can have shortcomings. The light levels recommended in Table 3, for instance, are generally higher than the 300 to 500 lx recommended by Marx et al. [106] for institutionalised people with dementia. New guidelines and standards that explicitly include older

people with dementia can also be used to raise the aforementioned awareness among professionals and managers.
Apart from the abovementioned standards and guidelines, used for the design of buildings, indoor environmental parameters and accompanying technology are also applied in the field of multi-sensory stimulation or 'snoezelen' [107-110], a therapy developed in the Netherlands around 1975 [111]. Multi-sensory stimulation is applied in a special room using numerous tools that offer sensory stimulation by light, sound, touch, smell and taste [108-110]. Apart from the therapeutic goals to make contact [110], multi-sensory stimulation also aims to offer pleasurable sensory experiences tailored to the needs of older adults with dementia [110]. Although Chung and Lai [112] have concluded in a Cochrane review that there is not evidence showing the efficacy of this therapy, multi-sensory stimulation is applied worldwide and appears in numerous handbooks and guidelines.

INSERT TABLE 3 HERE

5. Economic value

The domain of the economic value deals with the fit between demand and supply of solutions and cost-benefit analysis of improved indoor environments. Within the domain of the economic value, initial costs and operational costs, as well as maintenance, play a role as performance indicators. Apart from direct economic benefits to society that are the results from an integrated building design (macro level), there are the human benefits to individuals (micro level).

5.1. Raising awareness

One of the requirements for maximising the economic value is making all family and professional carers (and for that matter, managers in the health care sector too) aware about the role indoor environment might play in relation to behaviour and well-being. These persons can be made familiar through training as well as brochures, websites, handbooks, standards and guidelines, which have been shown to be lacking or incomplete at present. Training is costly and poses financial restrictions in the start-up phase. The results of training however, may cut down on costs for the processes of facilitating care. Raising awareness can lead to emancipation among carers and persons with dementia alike, which in turn should lead to requesting supportive indoor environments. In addition, managers in health care have an important role to play in the creation of such indoor environments.

5.2. Design

The economic benefits of good indoor environmental quality can also be threatened by new or emerging views in terms of the design of the home environment, such as the example of new healthy lighting systems provided by Calkins [113]. Such systems have obvious benefits to the residents of institutional settings. Calkins [113] stated that there is a shift away from discrete behaviours and single environmental 'solutions' to a more holistic approach. In her view, this represents a step forward in terms of understanding the larger, more complex set of relationships found in dementia care settings. Calkins [113] continues by providing an example of this more holistic approach, namely the creation of so-called home-like care environments, which include the absence of ceiling-mounted fluorescent lighting. At the same time, fluorescent lighting is used in healthy lighting systems [88-92], which have non-visual

health benefits to the residents unlike the more home-like and dim incandescent lights that provide a pleasant atmosphere.
Another issue related to providing solutions to existing demand is the availability of specialised technology. For instance, there are few commercially available solutions to assist people with dementia at home. One should keep in mind that what is available on the marketplace is not the same as what is or may be possible in practice [114,115].

5.3. Costs

There are economic aspects related to the creation of supportive indoor environments, which manifest in terms of benefits related to ageing-in-place and the reduced need for institutional care, the lessened burden on family carers, and the costs of home modifications.
Duijnstee [116] showed that practical housing can decrease the objective burden of family carers, and thus lead to human benefits, which also represent an economic value. Most family carers have an intrinsic motivation to provide care for a relative, but it is not a free choice. Moreover, many family carers are older adults themselves, and health problems may arise from the stresses of caring for a loved-one, in particular, when problem behaviours are observed. When family carers can no longer keep up with providing care due to all the stressors, people with dementia are institutionalised. New initiatives in the field supportive housing may offer opportunities for delaying the need for institutional care, which has economic consequences for both society as a whole as on an individual level. It was shown that for the Netherlands, € 6,000 to € 16,000 could be saved per person, depending on the health status, if people aged-in-place instead of being institutionalised (2004 price level) [117]. The human benefits of supportive living environments include increased well-being among people with dementia, support of family carers in the provision of care, as well as the opportunity that family carers do no longer have to cope with building-related or building-induced problem behaviours of their loved-ones.
If people with dementia are able to age-in-place, due to improved indoor environmental quality and building systems, instead of living in an institutional setting, this goes together with a reduction of costs for society. Van Hoof et al. [6] provide an overview of the financial and societal costs of care for people with dementia for the Netherlands. The costs of informal care in 2005 were an estimated € 4,700 per person with dementia per annum. The direct costs of dementia care were about € 14,200 per person with dementia per annum. The costs per person can vary considerably, even within the more developed countries and when considering the net domestic purchase power.
The availability of supportive home environments, in combination with adequate professional care, services and telehealth, is not only much wanted by people in the community, but also a necessity from an economic point of view [114,115].

INSERT TABLE 4 HERE

6. Synthesis of building-related solutions in the domain of the basic value

In the preceding sections basic value indicators were analysed which result from the needs of people with dementia. There are many building-related solutions available within the domain of the basic value that deal with the symptoms of dementia: impairments in activities of daily life, behavioural problems, and loss of cognitive functions. These solutions in relation to (i) air and odours, (ii) light and lighting, and

(iii) the acoustical environment (Table 4) are described per building system (Brand's six S's [20]: stuff, space-plan, services, skin, structure, and site) in the following paragraphs. The majority of the solutions presented are generic and may help the total population of perspns with dementia, whereas other solutions provide an answer in specific cases that depend of the health status, home environment and financial situation of the person with dementia. In practice, needs of the persons with dementia may vary due to differences in the stage of dementia, the incidence of problem behaviours, and health effects of biological ageing. All the aforementioned factors play a role when choosing and implementing a certain solution.

6.1. Air and odours

There are many building-related solutions available to the homes of older people with dementia to deal with odours and indoor air quality.

6.1.1. Stuff

Building-related solutions on the stuff level can be found in the field of floor covering and upholstery. Aromatherapy activies are part of this system, as well as artificial deodorisers.

Unpleasant smells (urine, strong cleaning products) are known to cause overstimulation [118], and should be removed from the home as much as possible. Textile floor covering and furniture upholstery, often chosen to create a home-like atmosphere, should be easy to clean when dealing with incontinence and leakage. At the same time, textile floor covering is also recognised as a source of volatile organic compounds, and is a dust reservoir containing biological contaminants like mites and moulds [119].

The sense of smell often seems to have a strong hold on human emotions, because of the connection to the limbic system, which is associated with emotion and memory processing [34,47]. Smells can therefore be used for reminiscing and aromatherapy activities. Aromatherapy has emerged as promising treatment for behavioural problems in dementia in institutional settings, since it is claimed to reduce stress and affect mood. Previous studies have found improvement in agitation, and motor behaviour [107]. During bathing, people with dementia could enjoy the smell of nice soap or bathwater with fragrance [100,120], which can alleviate stress. Perfumes as well as non-poisonous plants and flowers in and around the home can be used to alleviate stress, for example by reminiscing. People with dementia may be unable to recognise inedibles, and in some cases may even try to eat these items not intended as food. This probably results from damage to perception and memory [2,120]. Artificial deodorisers are no substitute for good ventilation, and may even pose dangers, for instance, when people with dementia mix up a bowl of potpourri for savoury snacks [36].

6.1.2. Space-plan

As smells can be used for reminiscing, pleasant odours can be a positive aspect of the home. Olfactory cues could even serve as orientation aids [121]. Some even claim that smells can improve wayfinding, for example, locating the kitchen via cooking smells [23]. Olfactory sense activation, for instance, by exposing people to cooking smells from the adjacent kitchen [2,118,122], improves appetite and food intake by stimulating the salivary glands [45], and hence can result in weight gains.

6.1.3. Services

Building-related solutions on the services level can be found in the field of ventilation systems and alarm systems.

A study by Coelho et al. [123] revealed that many older adults (without dementia) use many different cleaning products, spend a long time cooking (moisture and combustion products), and spend a great deal of the day indoors. This exposes them to many indoor air pollutants. Homes for older people with dementia can greatly benefit from an adequate ventilation system [121]. At the same time, cooking odours can have beneficial effects and should not all be taken out through the hood.

Ventilation is very important during bathing, in order to let fresh air in and to limit the amount of moisture that can cause hazardous mould growth. Brawley [124] mentions that during bathing, steam-filled rooms may be stressful for people with dementia.

Automated ventilation systems may be an option to get rid of excess moisture, but can problems of their own. Steinfeld [125] describes how his demented father got anxious by the noise generated by the fan that activated automatically when the light was turned on. The old man did not understand the source of the noise, as he turned on the light, not a fan. The anxiety was thought to increase by the acoustics of the bathroom. In this example, improvements to IAQ can lead to problems caused by inexplicable and loud sounds.

Smell and fine taste serve as a warning of environmental hazards [1]. A decreased sensitivity to odours may be dangerous for the older person, and can contribute to the inability to detect the odour of leaking gas, a smouldering cigarette, or spoilt food or something inappropriate [1,36]. Therefore, alarms may be helpful in the home environment. When the fridge’s temperature control knob has been handled, leading to too high a temperature inside, a temperature alarm may alert the carer [36]. In kitchens that have gas cookers installed, gas alarms may be helpful. The same goes for smoke and fire detectors [2,25,120]. Other alarms, for CO, CO_2 and NO_x are available too. These measures give early warnings in case of danger, but it is not always clear if the alarms are understood as a warning signal.

6.1.4. Skin

Building-related solutions on the skin level can be found in the field of ventilation systems in façades. When installing these systems, attention should be paid to the safety of the person with dementia and the family carer.

Opening windows and doors for ventilation purposes allow people with dementia to escape or climb out [2]. Openings should be small enough so residents cannot crawl through them to the outside [126]. Locks may be necessary on windows to keep them from being opened too far, or to keep residents from opening them throughout the winter [126]. Bars and locks may form restraints to residents, whereas ideally some windows in a home should be operable by the residents as an easy way to have a certain degree of control over the environment [126] and to allow for ventilation. Moreover, ventilation grids should be easy to reach, in order to prevent the risk of falls.

6.1.5. Structure

Building-related solutions on the structure level can be found in the field of a building’s floors. Olfactory dysfunction can also have social implications, with disadvantages to the person with dementia, relatives, carers and the social network. Ebersole et al. [1] and Diesfeldt et al. [46] state that people experience habituation to, and unawareness of, the own body odour. In case of incontinence, people may be unaware of the smell of urine that accompanies them [1]. In case of severe leakage due to incontinence, the concrete slab or sub-floor may be sealed in order to prevent odours from penetrating [127].

6.2. Light and lighting

The older individual is not static in the environment [43], and this is very important in creating supportive visual environments. People often look away from a visual task; areas that may be brighter or darker than the task and which affect visual comfort. Schiff et al. [99] state that excess visual stimulation can distract people from focussing on what they need to do in order to complete a task. In order to carry out visual tasks comfortably, attention should not only be paid to light levels, but also to luminance ratios, light colour, and colour rendering index.

6.2.1. Stuff

Building-related solutions on the stuff level can be found in the field of floor covering inside the living environment.
Highly polished floors are a common source of glare and should be avoided or replaced by matt surfaces [23,27,28,118]. Brawley [128] mentions that carpets can be used to control glare. Qualitative research by Hyde [96] involving Alzheimer's facilities staff, found that glare caused by bright overhead lights on overly waxed linoleum tiles caused 'puddles' of light that more than one informant reported residents walk around. The choice of floor covering is thus very important in glare control. As mentioned before, the application of textile floor covering may have consequences to IAQ, cleaning and mobility, as should therefore be applied with caution.
Calkins [126] mentions that table lamps should be heavy, and that one should consider cages around the bulbs. This would increase the safety of the lighting and prevent hoarding of the lamps, a behaviour occasionally seen in middle stages of dementia.

6.2.2. Space-plan

Building-related solutions on the space-plan level can be found in the field of daylight access and sightlines. Open floor plans allow for increased daylight access.
In order to deal with clinging behaviour, both residents (and carers) should have an overview of spaces to keep in contact with one another. Such sightlines can be created with an open floor plan, which is obtained by reducing the number of walls [5]. Some residents with dementia may face difficulty in locating the toilet when needing to visit this facility. It is assumed that toilets are easier found (and thus used) when clearly marked or visible from the living room [5].
It is important that older adults frequently go outdoors in order to be exposed to daylight. Special architectural arrangements including a sheltered outdoor terrace and easy outdoor access can be made. In a paper on environmental design for dementia, Brawley [129] asks herself: "*Why are we not focusing on the reasons older adults in nursing homes do not get outside for valuable and much needed sunlight?*" Exposure to daylight can be supplemented by special ceiling-mounted lighting [91].

6.2.3. Services

Building-related solutions on the services level can be found in the field of lighting systems and glare control, ballasts of lighting systems, the number and positioning of outlets control systems, and ceiling-mounted luminaires that can be used for light therapy.

Apart from raising general light levels indoors (Table 3), Mace and Rabins [2], Blom et al. [25], Burton and Torrington [28], Brawley [34,80,127,129], Warner [36], Boyce [50], Cluff [121], Silverstein et al. [130], and Gitlin [131] state that lighting should be consistent and evenly distributed to eliminate areas of shadow and glare. Moreover, glare from lights should be eliminated, and gradual changes in light levels and focused task lighting should be provided. Since many seniors have difficulty identifying the boundaries of objects, lighting should be sufficient to read any visual contrast in the environment [121]. Increased light levels, by up to 3 times, in combination with reduced glare and the use of contrast are means of adapting the environment for age-related changes in vision [35].
According to Turner [24], Blom et al. [25], and Brawley [34] consistent and bright light sources may help to eliminate frightening shadows cast by objects in the room, avoid distraction, and lessen the number of hallucinations. Dim shadows and glare can distort images even further, contributing to a resident's hallucination [34]. Of course, glare should not be countered by decreasing the general light levels [23].
Turner [24] adds that lighting should not be too bright, since it may hurt the sensitive eyes of older adults and cause tearing. Moreover, the lights may be the reason why someone refuses to look in a specific direction.
In kitchens and dining rooms, lighting should increase safety on the work blade. The dining area itself should be well lit in order for people to see and appreciate their food [2,120]. The lighting should not be overpowering or glaring [36]. Extra lighting in the cupboards could help people find food or utensils, and the same strategy could be used in closets to help find clothes. A study by Brush et al. [132] of the effects of modifications to lighting on nutritional intake and behaviour during dinner of two groups of institutionalised older adults with dementia, showed that higher light levels increased caloric intake in one group, and resulted in more conversations during meals. Similar studies need to be repeated in home settings to confirm the positive effects of lighting during mealtime.
Increased levels of lighting in bathrooms could help to prevent fall incidents. Since people are (un)dressing and grooming in bathrooms, there should be enough light to facilitate this activity [133]. The latter is also true for bedrooms. When people get out of bed at night to go and visit the bathroom, the path to the bathroom should be well-illuminated [36] to limited to risk of fall incidents. This need for lighting is illustrated by van Berlo [134], who describes the case of a woman, aged 56, who cares for her 88-year-old mother-in-law with dementia (pathology not mentioned). "*She can still handle the lighting. At night she leaves a small compact fluorescent lamp on. I once told her: 'Mom, you should leave it on, in case you got to go to the toilet at night'…*"
At night, lighting may help to prevent fear. This is illustrated by van Berlo [134] in a case of a 45-year old woman who cares for her 86-year-old mother with probable AD. "*I put her in bed and leave the lights on. I leave more lights on over time. It's a bit like a child's fear that a light needs to be on.*"

Brawley [80] mentions that flickering of old-style magnetic ballasts may cause agitation and headaches and can even trigger seizures, and therefore need to be replaced with electronic ballasts.

Warner [36] mentions the need for extra outlets for bedside electrical appliances that do not only include a table light, but also communication devices and a clock.

Brawley [129] calls for the need for daylight and glare control, for instance, through electronic dimmers or step-level switching for lower illumination levels at night. In general, lighting systems should be equipped with dimmers in case people with dementia experience overstimulation from excess lighting, or in order to create a more home-like atmosphere. Lighting in the bathroom should provide an enabling and restful atmosphere, and therefore, lighting should be dimmable [120]. Lighting should be operable from bed and near the door, and should be equipped with dimmers [36]. Light switches should be of the pressure-plate type instead of handle-type switches [122].

For institutional two-person rooms, Calkins [135] suggests using separate lamps for each resident, which he or she can turn on and off. A similar strategy may work for couples at home as well. Extra night-lights could be a solution to increase safety at night when going to the bathroom [120].

Van Berlo [134] provides two examples of people with dementia and the challenges posed in relation to switches. First, there is the case of a 45-year old woman caring for her 86-year-old mother with probable AD. "*[S]he sat in a low chair that was hard to get out of. […] We also placed the button of the floor lamp on the armrest, because it used to be somewhere low and that was somewhat of a burden. So we moved it, so that she can reach more easily.*"

Second, there is a 64-year old woman, who cares for her husband, aged 65, who is diagnosed with probable AD. "*He walks around for six times, before he finds the switch. I mean, I don't let him become tired from such things. […] If I'd say, 'Please turn off the lights', then he has turned to four to five plug sockets, before he reaches the right light switch. Then I need to direct him: 'There, forward, to the right'. […] I want to let him do it by himself, but I really need to give him directions.*"

The increase of the general illuminance level in rooms where people with dementia spend their days via the installation of ceiling-mounted luminaires is gaining increased attention [88-92]. More research and modelling are needed in this field, as current illumination systems are not suitable, or user-friendly, for exposure to the required high levels of lighting. Carswell et al. [136] suggest that these special luminaires may not only positively impact people with dementia during the day, but also have a role to play in nighttime care.

6.2.4. Skin

Building-related solutions on the skin level can be found in the field of façade systems for daylight access and glare control.

Glare from windows should be eliminated, and access to natural daylight should be provided, for instance as an orientation aid, along with gradual changes in light levels. Care should be taken to avoid glare from low-elevation sunlight [28]. Proper curtains and window shades can help to control the visual environment [21,23,25].

In order to provide daylight, as well as cues on the outdoor environment, bathrooms should preferably be equipped with an outside window [34].

It is important that people get enough rest, which should be the number one priority when designing and decorating bedrooms [2]. Heavy curtains, as part of the façade system, can be put in place to keep light out [25]. Blinds and screens could also be applied.

Tilly and Reed [102] stress the importance of regular sleep-wake cycles and state that these should be encouraged by ensuring that residents are exposed to sufficient daylight, apart from keeping bedding dry.

6.2.5. Structure

Building-related solutions on the structure level can be found in the field of the design of the façade and the installation of heavy luminaires. Large windows allow for the access of daylight and allow people to look outside. Bowlby Sifton [38] states that windows can help in offering reality reassurance by providing outdoors views that help with orientation to the season and time of day.

The structure of the ceiling should be sufficiently robust in order to carry the load of ceiling-mounted luminaries needed for light therapy.

6.3. The acoustical environment and noise

The building-related solutions available in relation to the acoustical environment and noise aim at reducing background noise in the various rooms in the home, and improving the acoustical environment via the use of specific sound-absorbing materials. There are no concrete data or design guidelines on optimal sound pressure levels and reverberation times for home situations yet. Acoustical engineers should be able to distil relevant design information from the practical situations mentioned in the following sections.

6.3.1. Stuff

Building-related solutions on the stuff level can be found in the field of the application of sound absorbing materials in the living environment.

A common strategy to limit reverberation times indoors is the placement of sound absorbing curtains and textile floor covering [127,128,137]. Floor covering should not only be bought based on the acoustical properties, as it also has an impact on IAQ. Thick textile floor covering is uneasy for wheelchairs and walkers [36], and should be resistant against heavy use. When cleaning is required, the sound of hovering can be frightening. Another issue with textile floor covering is that some people may experience disorientation or vertigo in response to large, bold geometric patterns [34]. Certain patterns may lead to nausea. Patterns may not be perceived to be level, or actually seem to move leading to instability [34,100] or stalling. Such covering should not be used in other to minimise the risk of fall incidents.

6.3.2. Space-plan

An open space-plan can improve wayfinding, as people can use auditory cues for orientation. At the same time, open space-plans have implications to reverberation times and sound propagation in the dwelling. For instance, open kitchen areas could also cause overstimulation in the living room due to sounds produced by a kitchen hood.

6.3.3. Services

Building-related solutions on the services level can be found in the field of limiting background noise and music coming from electronical equipment.

In care settings, people with dementia are exposed to very high levels of intrusive and disturbing aural stimulation, including intercoms, telephones, paging systems and alarms [11,21,27,100,122,129], and unfortunately this is often the case at home as well. Hayen and Gafford [138] mention the importance of a quiet institutional environment, with tempered loud talking, radios and televisions, and a selection of background music that soothes the residents rather than entertain carers.

Many studies call for a reduction of excessive noise levels (for instance, [28,38,129,131]). Moreover, assistive devices as 'talking' toilets and mirrors can be a source of confusion, and should be introduced into the dwelling with great caution.

To many older adults with dementia, the bathroom is a place that can cause great stress, partly because of sounds and acoustics. According to Warner [36], it is important to consider problematic sounds that may be confusing or irritating, including rushing water, the toilet flushing, exhaust fans and HVAC systems, washing machines, and outside noises, such as traffic or people [34,36,139]. Inside the bathroom, whirlpools can cause fear and agitation because of the sound they produce [34]. When using a radio, one should consider the danger of electrocution, as with any electrical equipment used in bathrooms [120].

During the preparation of meals and dinner, sound can be distracting too, such as background noise, and sounds from radios, televisions [120] and kitchen hoods. In dining rooms, excessive background noises from dishwashers and other kitchen sounds should be limited [36]. If televisions and their sounds cause loss of concentration, fear, agitation or panic, also due to misinterpretation, they should be put off, and soft music could be played [23,25]. Larkin [140] states that music also improves autobiographical recall, and has greater facilitatory effect than either quiet or background noise. Background noise should be kept to a minimum in order to assist with concentration. When talking to a person, one should not compete with a television or a radio [24], since the person with dementia is usually not able to focus on both voices at the same time. It only adds to the state of confusion. At the same time, radios may be a source of therapy. Burgio et al. [141] studied an interventions including listening to white noise; audiotapes of nature. Results indicated a 23% reduction in verbal agitation in severely demented nursing home residents (n=15), albeit that the results were obtained despite poor treatment fidelity. Radio-like interfaces are also used for reminiscence activities and leisure, for instance, by van Rijn et al. [142].

Finally, fire alarms that are installed for reasons of safety should be loud enough for older persons to be heard (sound pressure level about 74 dB(A)), even though some persons may have difficulty recognising the signal [143].

6.3.4. Skin

Building-related solutions on the skin level can be found in the field of façade systems to reduce indoor noise levels.

Reducing background noise starts with the home's façade. When people live near a crowded street, traffic noise can be kept out by having windows shut or having thermally and acoustically insulating panes. At the same time, auditory clues may be used as orientation aids [121].

The role of sound in bedrooms is evident. A silent bedroom is crucial to good sleep, which is of great importance to both the person with dementia as the caring partner. Both Warner [36] and Mace and Rabins [2] stress this need. Apart from the need for a proper sound-insulation building construction, one could also buy heavy curtains that not only keep the sun, but also noise, out of the bedroom [25].

6.3.5. Structure

Building-related solutions on the structure level can be found in the limitation of reverberation times through the choice of building materials and finishings.

In case ceilings are dry wall, one can install acoustic panels on walls [127,128,137]. To many healthy people, bathing is an activity of relaxation. Stress and agitation may be reduced by singing together during bathing [120]. Bathroom acoustics may be great for singing in the shower, except for those who are irritated or upset by noise bouncing around in hard, ceramic tile environments [36]. In order to improve the room acoustics, bathroom finishing materials should be chosen with care in order to reduce the reverberation time as much as possible, even though out of hygienic reasons ceramic tiles are the best option.

7. Conclusions

Older people with dementia may perceive the indoor environment differently from counterparts without dementia, which can go together with certain behavioural symptoms. People with dementia are not just seemingly passive receptors of the indoor environment, but may actually respond to it in a very outspoken manner, and that technology installed may actually pose challenges to the provision of care and well-being.

The design solutions that followed the identification of needs in the domain of the basic value, may be a first step towards evidence-based and stakeholder-related design of home environments for people with dementia. Of the three indoor environmental parameters treated in this paper, light is the best understood. Novel lighting applications are developed and applied to improve cognition, mood and behaviour, sleep and vision. Vision can be improved by raising general illuminance levels and glare control. The economic benefits are thus largely visible for the relevant stakeholders, although in practice not all older people with dementia have access to such lighting systems or are sufficiently exposed to daylight. The supply of fresh air, elimination of bad odours, reduction of background noise and other aspects of the acoustical environment are recognised as being important to behaviour and well-being of people with dementia, but are not as well-understood as light and lighting. The economic benefits of accounting for these parameters are not yet clear. More research is needed on how and which odours impact well-being and behaviour positively and negatively, and what the acceptance thresholds are. Also, adequate ventilation systems should be developed to counter the negative effects of odours without causing distress by noise. In terms of the acoustical environment, it is not possible to provide specific data and values of the ideal sound pressure levels and reverberation times for persons with dementia. The types of noise that may cause distress are not always predictable. The acoustical environmental is claimed to improve wayfinding, although the underlying mechanisms are not fully understood. More research is needed in these fields.

The new framework combining the International Classification of Functioning, Disability and Health and the Model of Integrated Building Design was a useful tool for a detailed analysis of various stakeholder-related needs and solutions on a building system level, bringing together demand and supply and adding a new dimension to the care of persons with dementia. The synthesis of building-related solutions does not yet provide an overview based on existing guidelines, but provides directions for home modifications in relation to the three values considered in this paper. Given the results of this study, it is worthwhile to investigate and evaluate the impact of the indoor environmental parameters on older people with dementia further along the lines indicated. In addition, further research is needed to explore the functional and economic values of the described environmental parameters as solutions for persons with dementia and their informal and formal carers.

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Table 1. Cognitive and behavioural problems found among people with dementia [2,34-37].

• illusions • hallucinations • delusions • impaired wayfinding • difficulties understanding • loss of self-confidence • poor judgment • inability to recognise • impaired sense of time • disorientation • fear of bathing and water • personality changes	• agitation • suspicion • loneliness • depression • restlessness • misplacing items • hiding things • hoarding • rummaging • shadowing • dependence • resistance	• aggression • withdrawal • declining social skills • eating inappropriate items • abnormal sexual behaviour • wandering • repetitive actions • sundowning • catastrophic reactions • paranoia

Table 2. Age-related sensory changes to smell and taste, vision and hearing, and outcomes.

SMELL AND TASTE [1]

- Decreased olfactory cells, may lead to decreased appetite, and decreased protection from noxious odours and tainted food.
- Possible decrease in size and number of taste buds, may lead to poor nutrition.

VISION [1,43]

- Lid elasticity diminished, leading to pouches under the eyes.
- Loss of orbital fat, lead to excessive dryness of eyes.
- (i) Decreased tears, (i) arcus senilis becomes visible, (iii) sclera yellows and becomes less elastic, (iv) yellowing and increased opacity of cornea, may lead to a lack of corneal lustre.
- (i) Increased sclerosis and rigidity of the iris, and (ii) a decrease in convergency ability, lead to presbyopia.
- Decline in light accommodation response leads to lessened acuity.
- Diminished pupilary size leads to a decline in depth perception.
- Atrophy of the ciliary muscles (holding the lens) leads to a diminished recovery from glare.
- Night vision diminishes leading to night blindness.
- Yellowing of the lens may lead to a diminished colour perception (blues and greens).
- Lens opacity may develop leading to cataracts
- Increased ocular pressure may lead to seeing rainbows around lights
- Shrinkage of gelatinous substance in the vitreous, may lead to altered peripheral vision.
- Vitreous floaters appear.
- Ability to gaze upward decreases.
- Thinning and sclerosis of retinal blood vessels.
- Atrophy of photoreceptor cells.
- Degeneration of neurons in visual cortex.

HEARING [1]

- (i) Thinner, drier skin of the external ear, (ii) longer and thicker hair in the external ear canal, (iii) narrowing of auditory opening, (iv) increased cerumen, (v) thickened and less resilient tympanic membrane, and (vi) a decreased flexibility of the basilar membrane, may result in difficulty hearing high-frequency sounds (presbycusis).
- (i) Ossilar calcification, and (ii) diminished neuron, endolymph, hair cells and blood supply to inner ear and auditory nerve may lead to a gradual loss of sound.
- (i) Degeneration of spiral ganglion and arterial blood vessels, and (ii) weakness and stiffness of muscles and ligaments may impair hearing.

Table 3. Illuminance levels per room [104]. Generally, the colour temperature of the light sources should be between 2,700 and 3,000 K, in accordance with personal preferences. Recommendations by De Lepeleire et al. [105] based on a 55% increase of levels stated in the European Standard Lighting of workplaces are included in the comments.

Location	Illuminance [lx]	Comments
Living room	200-300	Install extra light sources to create the desired atmosphere
Living room, near seat	1,000-2,500	At places where a great deal of time is spent, lighting for biological stimulation could be installed. The colour temperature should be between 6,500 and 8,000 K. A chair could be placed near the window.
Dining room (table level)	500-1,000	For eating, reading, leisure
Hobby and work space	500-1,000	De Lepeleire et al. [105] advise about 775 lx
Kitchen	300-500	Task illumination for food preparation, at least 1,000 lx
Bathroom and toilet	> 200	
Bedroom	100-300	Bedside light, about 1,000 lx
Corridors and storage rooms	100-200	Extra night lights (preferably red lights [80,104]). De Lepeleire et al. [105] advise 200 to 300 lx during day, and 50 to 80 during the night.
Stairs	> 200	Optional: install handrails that give off light. De Lepeleire et al. [105] advise 150 to 230 lx for stairs.

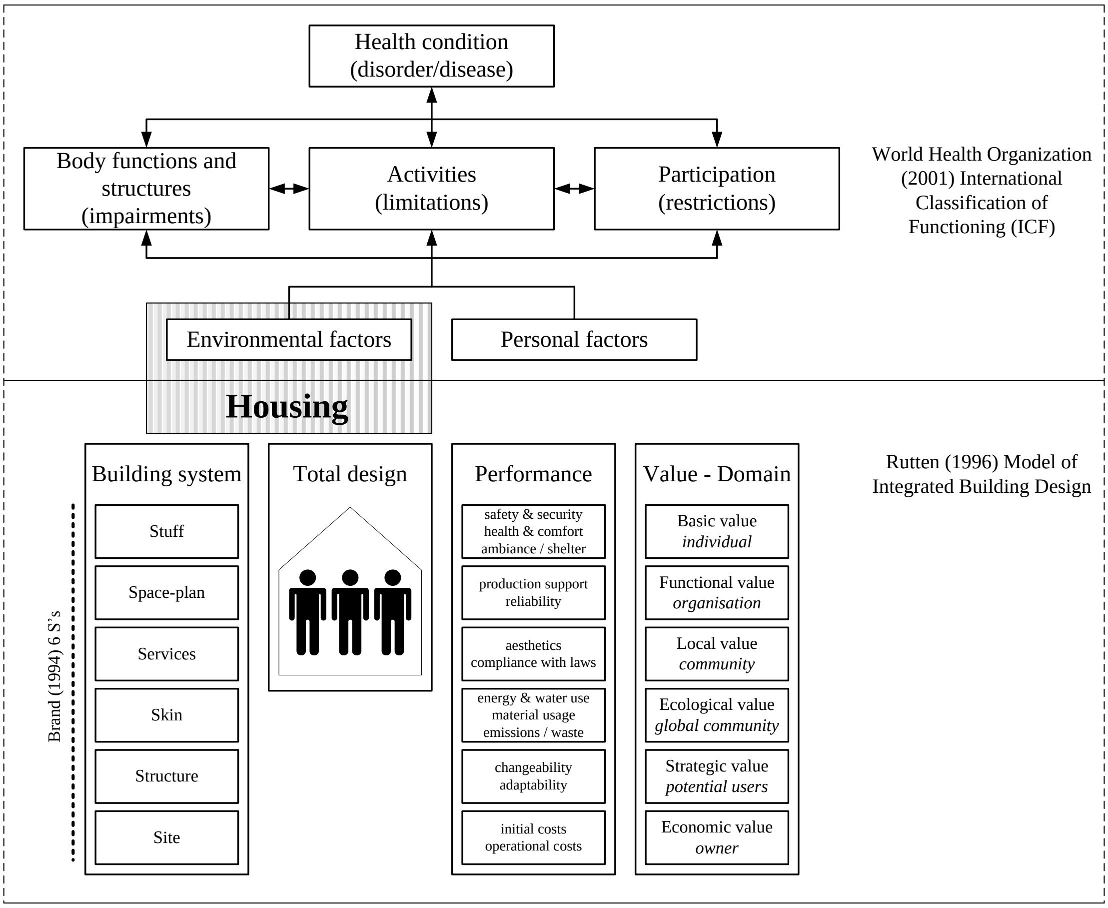

Figure 1. Interactions between the components of ICF by the World Health Organization [19], and the integration of the Model of Integrated Building Design by Rutten [14].

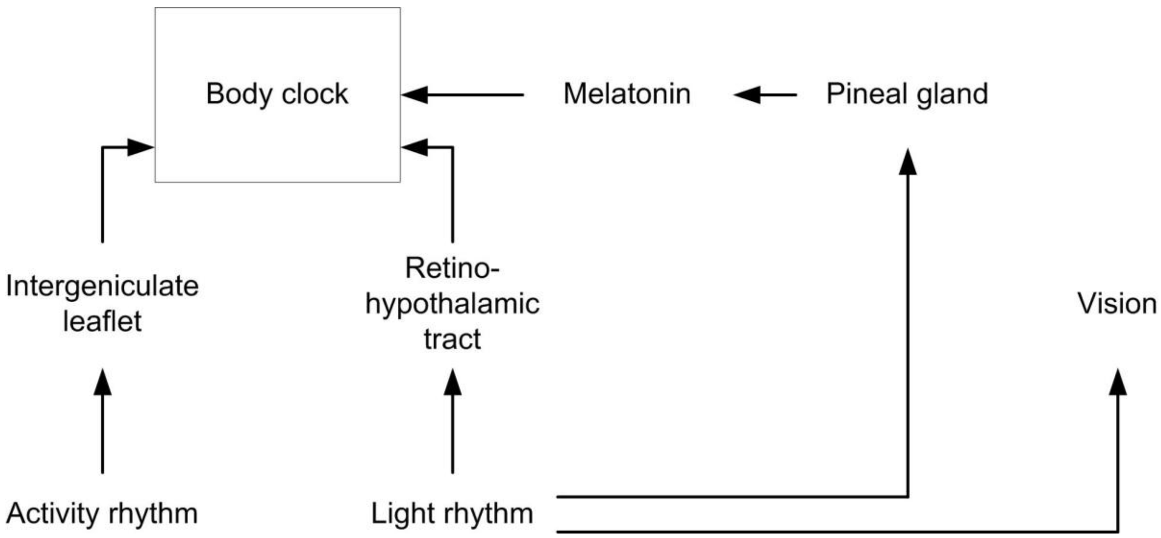

Figure 2. Simplified scheme of pathways by which light, melatonin, and activity rhythms act as *Zeitgebers*. Taken from Waterhouse et al. [64, p. 110].

Table 4. Basic value needs and their relation to building systems/solutions (economic value). Curtains can be part of stuff and skin, depending on their function.

Basic value needs	Building systems Stuff				Space-plan	Services							Structure	Skin			Comments
	Furniture	Floor covering	Curtains	Other items		Ventilation systems	Lighting	Alarm systems	Controls	Electronic equipment	Sanitary equipment	Other services	Floors	Ventilation systems in façade / operable windows	Curtains, shades and blinds	Windows / glass	
Odours -IAQ																	
Need for safety - Impaired odour identification								1									1. Install gas alarms, smoke and fire detectors. Alarms on fridge
Need for safety – Cognitive impairment				1				2									1. Avoid artificial deodorisers / potpourri 2. Install gas alarms, smoke and fire detectors. Alarms on fridge
Incontinence - Impaired odour identification	1	2											3				1. Easy to clean upholstery 2. Easy to clean floor covering 3. Concrete slab or sub-floor may be sealed
Need for ventilation			1	2		3								4			1. Prevent curtains from moving in draught (suspicion) 2. Prevent items as paper from moving in draught (suspicion) 3. Silent automated ventilation systems (low noise) 4. Small openings to prevent people from climbing through. Locks on windows. Easy to reach grids/windows
Olfactory stimulation and way-finding					1	2								3			1. Open kitchen. Stimulation of appetite 2. Prevent 'good' odours to be removed via hood or ventilation system 3. Prevent 'good' odours to be removed via hood or ventilation system
Light(ing)																	
Need to avoid glare	1	2	3				4		5				6		7	8	1. Mat upholstery and non-polished furniture 2. Avoid shiny floor covering 3. Type of curtain fabric may influence glare 4. Install consistent lighting. Do not lower light levels 5. Beware of automated glare control (blinds). May cause problem behaviour. 6. Avoid polished floors 7. Install curtains, shades and blinds 8. Special non-glare glazing. May lead to distorted colour perception and dark interiors
Need to avoid excess visual			1				2								3		1. Install curtains. Certain patterns can cause behavioural problems 2. Use electronic ballasts. Install dimmers

stimulation																3. Install curtains, shades and blinds
Need for increased light levels	1	2	3				4				5					1. White furniture reflects more light. Risk of glare 2. White floor covering reflects more light. Risk of glare 3. White curtains reflect more light. Risk of glare 4. Increased, consistent, light levels. Provide sufficient lighting at table level. (improve appetite) 5. Install additional outlets near bed 6. Access to windows
Need for access to daylight			1		2										3	1. Choose curtains in order to maximise and minimise daylight entry (when sleeping during day-time). 2. Open floor plan 3. Large windows (avoid over-heating). Windows also provide orientation cues (particularly in bathrooms)
Need for safety							1									1. Extra light in kitchen (near kitchen blade). Put cages around warm bulbs (touch). Heavy table lamps (hoarding)
Need for control over lighting			1				2							3		1. Curtains can help control daylight 2. Dimmers (particularly in bathroom). Lighting operable from bed and near doors. Separate lamps in bedroom. Pressure-plate type light switches. 3. Install curtains, shades and blinds 4. Special non-glare glazing. May lead to distorted colour perception and dark interiors.
Noise																
Need for low background noise (distraction, hearing impairment)								1	2				3		4	1. Limit amount of alarms when causing overstimulation 2. Limit amount of electronic equipment (tv, radios etc). Also during cooking/dining. Hovering may cause over-stimulation 3. Keep ventilation systems / windows closed to keep traffic noise out. 4. Install acoustically insulating panes
Need for sleep			1									2	3	4	5	1. Install heavy curtains in bedroom to keep (traffic) noise out 2. Structural composition of dwelling can contribute to silent bedroom 3. Keep ventilation systems / windows closed to keep traffic noise out 4. Install heavy curtains or shutters in bedroom to keep (traffic) noise out 5. Install acoustically insulating panes
Limit reverberation times	1	2	3	4	5							6				1. Add furniture 2. Add textile floor covering (impact on hygiene, IAQ, and wheelchair accessibility). Patterns can cause behavioural problems and falls 3. Add curtains. Certain patterns can cause behavioural problems 4. Add other items 5. Lay out of building (size of rooms) impacts reverberation times 6. Bathrooms are often tiled (ceramic tiles for hygiene). Dry-wall ceilings can be equipped acoustics panels
Need to reduce fear and stress (bathroom)						1			2	3						1. Limit noise from ventilation systems in bathrooms 2. Limit noise from washing machines 3. Minimise sounds from sanitary equipment in bathrooms. Avoid whirlpools
Need for safety – Cognitive impairment									1							1. Radio in bathroom may pose danger

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