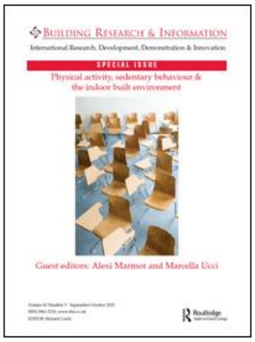

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# Healing built-environment effects on health outcomes: environment–occupant–health framework

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**ABSTRACT**
An investigation examined the structured scientific evidence on healthcare facilities (the healing built environment – HBE) and its impact on patients' health outcomes under a holistic conceptual evaluative framework. The integrative review considered 127 papers (of which 59 were review papers). It found there was no adequate framework that could integrate existing research findings holistically. Such a holistic framework needs to demonstrate the cumulative and interactive effects of various HBE characteristics on patients' health outcomes and wellbeing. An environment–occupant–health (E-O-H) framework is proposed, taking a holistic perspective to identify and evaluate different HBE characteristics. The E-O-H framework should support future research by (1) identifying the HBE characteristics that affect health outcomes; (2) defining appropriate future research designs; and (3) understanding the need for holistic analysis of the integrated effects of diverse HBE characteristics on health outcomes.

**KEYWORDS**
buildings; built environment; healing; health; healthcare facilities; occupants; outcomes; wellbeing

## Introduction

Health outcomes have been a central concern in evaluations of quality of life (Brazier, Ratcliffe, Saloman, & Tsuchiya, 2017). Many elements that support health outcomes have been identified by different disciplines, *e.g.* an individual's initiatives and lifestyles, social interactions in clinical and social care, quality of health and care services, as well as the physical environment (Street, Makoul, Arora, & Epstein, 2009; Twiss et al., 2003; Wilkinson & Graves, 2014). The physical environment, *e.g.* healthcare buildings, plays an essential role in supporting care services, individuals and their social interactions. However, it is difficult to identify what proportion of health benefits or outcomes can be attributed to the physical environment. Furthermore, it is challenging to identify how the interplay of a range of physical environment factors influences or contributes to health outcomes.

In this study, the term 'healing built environment' (HBE) is used. It is described as healthcare buildings that (1) reduce the stress levels for all healthcare building users; and (2) promote health benefits for users. This focus is in line with the definition of the 'healing environment' raised by Stichler (2001), which describes 'a physical setting … *that supports patients and families through the stresses imposed by illness, hospitalization, medical visits, the process of healing* … ' (p. 10, emphasis in the original). The definition refers to buildings that optimize and improve the quality of care, outcomes and experiences of patients and staff (Jonas & Chez, 2004; Sakallaris, Macallister, Voss, Smith, & Jonas, 2015).

There are a number of existing studies on the impact of the HBE on health outcomes. Table 1 outlines the scope and basic information of 10 literature review papers published after the year 2000 in peer-reviewed journals. These review papers took an overview of how the built environment affects healthcare building users' wellbeing and health outcomes, referring to over 250 academic journals/reports, hence providing an overview of the existing research.

These reviews are informative in updating the state of the art and include both quantitative and qualitative studies. Most existing studies tend to be very specific and often linear in investigating one built environment attribute in relation to one specific health outcome, *e.g.* the impact of sunlight on postoperative analgesic medication use (Walch et al., 2005). Another typical example is the debate of the benefits, or otherwise, gained from

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**Table 1.** Summary of integrative review papers from 2000 (publication order).

| | Reference | Years covered | Papers surveyed | Level of evidence rated | Review findings and implications for research with keywords in bold (selected) |
|---|---|---|---|---|---|
| A | Iyendo, Uwajeh, and Ikenna (2016) | Up to 2016[a] | 195 | No | **Sound** should be viewed from a social aspect as a positive addition to clinical settings. Creating a therapeutic space is closely dependent on and intertwined with many aspects, so more empirical studies on **multiple factors** are needed |
| B | Laursen, Danielsen, and Rosenberg (2014) | 1966–68. 2013 | 14 | No[b] | Not many articles in the field of environmental design are randomized controlled trials (RCTs). The built environment, especially **specific audio and visual aspects**, *e.g.* music, natural sound, murals, plants and sunlight, play an important positive role in patients' outcomes |
| C | Salonen et al. (2013) | January 1975–August 2012 | 214 | No | Most studies have focused on the effects of **physical environment factors**, *e.g.* light, noise, air quality. Additional studies focusing on **all user groups** and on the **interaction** between the physical elements are required |
| D | Huisman et al. (2012) | 1984–2011 | 65 | Yes | Evidence of **staff outcomes** is scarce and insufficiently substantiated. The main challenge will be to explore and specify staff needs and to **integrate** those needs into the built environment of healthcare facilities |
| E | Drahota et al. (2012) | About 2010 | 102 | No[b] | **Music** may improve patient-reported outcomes in certain circumstances, so support for this relatively inexpensive intervention may be justified. Future research efforts should focus on **improved methodological design** to reduce the risk of bias |
| F | Codinhoto et al. (2009) | About 2008[a] | 92 | No | A number of variables affect health **independently or in combination** with other variables, despite lack of clarity in relation to **cause–effect relationships** (*e.g.* stress was affected by noise, lack of contact with green/gardens and colour, while light might affect depression, melanoma and retinopathy) |
| G | Ulrich et al. (2008) | About 2004 | Not stated | Yes | A few design characteristics that have a **positive impact** were addressed, *e.g.* single-bed rooms, abundant daylight, views of nature. Future research should be **carefully designed and controlled** |
| H | Dijkstra, Pieterse, and Pruyn (2006) | About 2005 | 30 | No[b] | Conclusive evidence is very limited and difficult to generalize, *e.g.* the effect of nature, spatial layout, multiple stimuli interventions. The field appears to be in urgent need of **well-conducted, controlled clinical trials** |
| I | Schweitzer et al. (2004) | About 2004 | Not stated | No | A hierarchy of the environment's effect was postulated, ranging from **non-toxic to safe to 'providing a positive context' to being actively salutogenic**. Most relevant research has been concentrated on a limited number of settings and is inadequate to inform the creation of design guidelines |
| J | Devlin and Arneill (2003) | About 2002[a] | Not stated | No | **High-quality research** focused on healthcare environments is challenging. A new paradigm in healthcare architecture with structures that reflect **caring and flexibility** is needed |

[a]Latest publication in the reference, though not stated in the paper.
[b]Only controlled clinical trials were included in the review.

single-bed patient rooms (Van de Glind, de Roode, & Goossensen, 2007). It is challenging to integrate all HBE factors in a single-bed room (*e.g.* light, layout, furniture, floor covering); also, it is extremely difficult to control other, non-HBE factors (*e.g.* in-patient management, care providers' skills) Moreover, health outcome measures are complex and hard to define, even when studies focus on just one group of occupants (*e.g.* patients) and on one specific benefit (*e.g.* privacy).

Furthermore, in general terms, four main issues are highlighted across the studies. Firstly, the majority of published studies focused on sensory environments: thermal, acoustic, visual and air quality (A–C in Table 1). Secondly, there is a need for more studies across all user groups, especially staff (CD in Table 1). Thirdly, the strength and quality of evidence is varied in terms of the degree of robustness of each specific study (BDG in Table 1). There is a clear argument for the need for more well-conducted, controlled experiments to be developed (BEG–J in Table 1); however, there is also a clear recognition that it is challenging to determine high-quality research designs in the area (BGJ in Table 1). Finally, reviews emphasize the importance of identifying the interaction between diverse variables and the need to consider those in an integrated way (CDFG in Table 1).

Importantly, the reviews highlight the lack of a methodological approach that integrates the available evidence. The main difficulty is that HBE studies approach knowledge from a multitude of disciplines with varying strategies for knowledge generation, varying from (non/quasi-)experiments to fully qualitative studies (interviews, observations *etc.*). It is challenging to conduct rigorous studies in this area mainly due to the multiple factors that influence it.

Therefore, as a consequence of the way that research has been undertaken to date, it is not possible to discuss the importance of a particular design feature in relation to others, nor could research findings inform designers as to how to locate resources to achieve more effective design solutions. For these reasons, research is needed to explore the impact of multiple HBE factors from a holistic and dynamic perspective (Durmisevic & Ciftcioglu, 2010; Nimlyat & Kandar, 2015).

The integrative review presented in this paper intends to make a contribution towards the aforementioned holistic research direction. This paper does not attempt to replicate the collection of all the evidence that has already been incorporated into earlier reviews. Its objective is to *propose a method to build a flexible and dynamic framework that integrates HBE characteristics, taking a holistic perspective to support future empirical studies*. The following questions were explored in the study:

- Which environmental characteristics relate to healthcare facilities occupants' health outcomes or benefits?
- How can existing research findings be integrated and structured holistically?

This paper is structured as follows. The research method is outlined in the next section. The preliminary version of the proposed holistic conceptual framework for evaluating health outcomes associated with the HBE is then presented in the third section. The main body of this review is given in the fourth section in the format of tables, synthesizing HBE characteristics and its impact on health outcomes. The final version of the framework is presented, and conclusions and recommendations provided, in the final section.

## Methods

Systematic literature reviews are used to summarize the results of existing studies as well as to access existing studies in a systematic, transparent and reproducible manner (Petticrew, 2001). Systematic reviews differ from traditional narrative reviews by adopting a replicable and transparent process (Cook, Greengold, Ellrodt, & Weingarten, 1997). A systematic review aims to answer a specific question, to reduce bias in the selection and inclusion of studies, to appraise the quality of the included studies, and to synthesize them objectively (Tranfield, Denyer, & Smart, 2003). In this research, a mixed approach is adopted incorporating elements of a systematic literature review, aiming to increase the rigour of the review as well as to support the identification of relevant studies to be included. The research design adopted is presented below.

### *Research design*

The aim of this review was to identify HBE characteristics that impact on health outcomes and use these to develop a holistic framework. Therefore, an iterative research design was employed (Figure 1). The six research steps undertaken are described as follows.

#### *Step 1*

The review started by identifying previously published literature reviews. PubMed, Scopus, MEDLINE, ScienceDirect and Google Scholar were the databases used to identify relevant articles. The search was performed using the keywords 'evidence-based design', 'healing environment', 'sensory/built environment', 'physical/clinical/hospital settings', 'design factors', 'wellbeing', 'health outcome' and 'health benefit'. The keywords were defined on the basis of the main research themes under investigation, and the search was conducted in October 2016.

#### *Step 2*

The screening process was done by reviewing the papers' title, abstract and year of publication. Only integrative literature reviews were included, published from the year 2000 onwards, written in English. The following inclusion criteria were also used:

- focus on healthcare buildings from small clinics to large teaching hospitals
- focus on design evidence about HBE characteristics, including internal and external spaces, which provide stimuli to affect the occupants' behaviour and/or health outcomes
- focus on patients, visitors and/or staff
- focus on measuring impact on occupants' wellbeing and health outcomes

In total, 19 full-text papers were obtained. Nine were excluded as their focus was outside the scope of this work; 10 review papers were included.

#### *Step 3*

The 10 integrative literature review papers were synthesized:

- to expand the justification of this research – the papers' selected findings are summarized in Table 1
- to support the early identification of HBE characteristics
- to develop a preliminary version of the environment–occupant–health (E-O-H) framework.

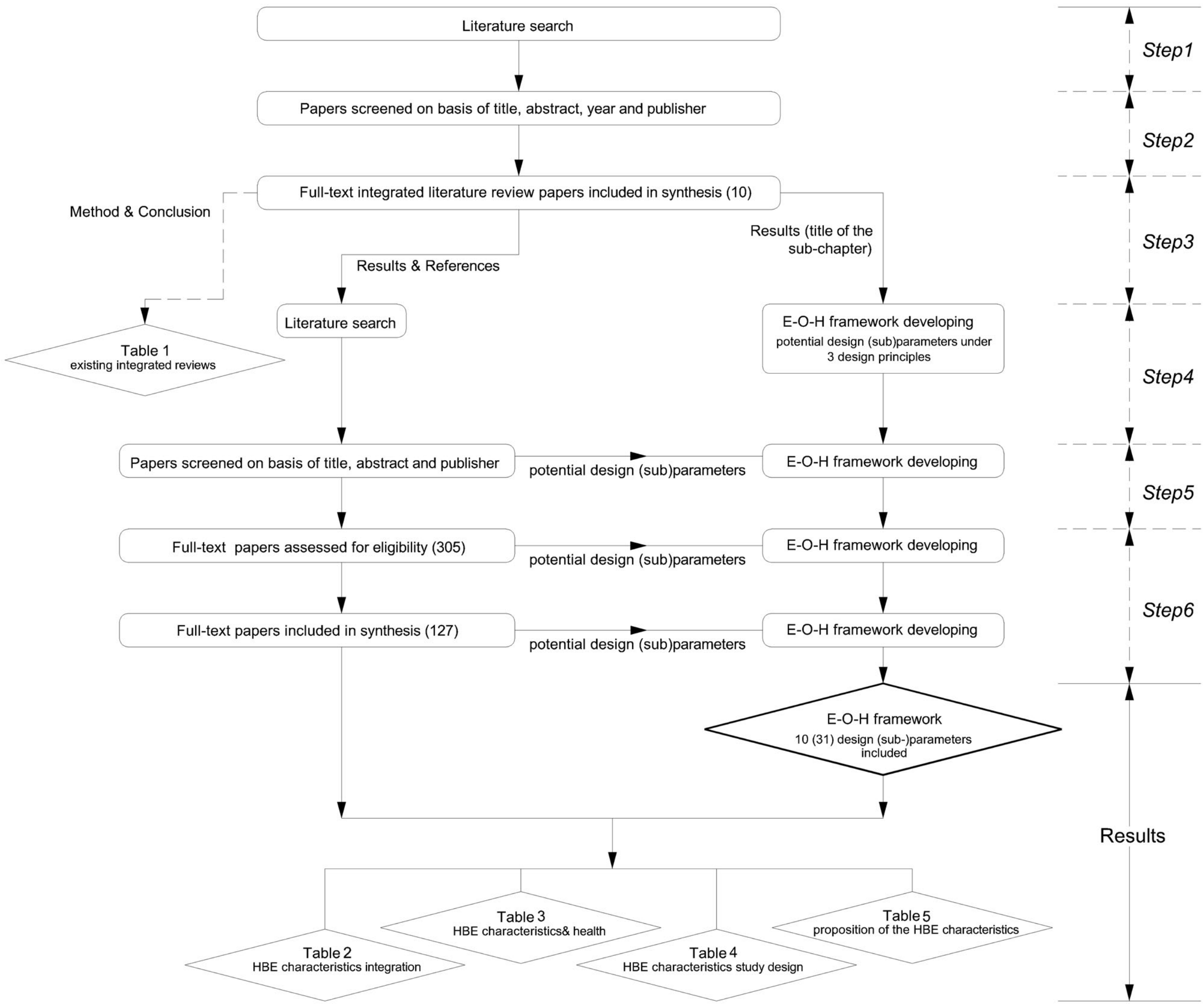


**Figure 1.** Research design.

### Step 4

A new set of keywords were identified to support a fuller database search. These keywords were identified from the results of the 10 literature review papers originally included. The databases used were same as described in step 1. A total of 42 keywords were used: ‘access to nature’, ‘acuity-adaptable rooms’, ‘artwork’, ‘acoustic environment’, ‘cleanliness’, ‘ceilings’, ‘colour’, ‘control’, ‘fabric’, ‘furnishings’, ‘ergonomics’, ‘family areas’, ‘floor coverings’, ‘furniture’, ‘garden’, ‘indoor air quality’, ‘landscape’, ‘light’, ‘maintenance’, ‘materials’, ‘music’, ‘noise’, ‘nursing station’, ‘odour’, ‘patient-centred care’, ‘privacy’, ‘safety’, ‘seating’, ‘single-bed patient room’, ‘social support’, ‘sound’, ‘spatial layout’, ‘staff area’, ‘sunlight’, ‘temperature’, ‘thermal environment’, ‘treatment areas’, ‘ventilation’, ‘view’, ‘visual environment’, ‘waiting rooms’, ‘wayfinding’, ‘healthcare/hospital settings’, ‘environment’ and ‘building’.

### Step 5

The screening process included reviewing papers’ titles and abstracts to identify their fit to the research. After this initial screening, 305 papers were included.

### Step 6

The 305 papers were read. The review focused on the research purpose and how the studies were carried out. Inclusion/exclusion criteria included:

- For review papers, the inclusion criteria were: (1) a focus on reviewing a specific HBE characteristic and its impact on health outcomes, *e.g.* a review of the impact of air quality on health; OR (2) a focus on reviewing diverse HBE characteristics’ impact on a specific health outcome, *e.g.* a review of the environmental factors impact on quality of sleep; and (3) recent publications (*i.e.* after 2010) in order to identify research trends.

- For empirical studies, the inclusion criteria focused on the rigour of the studies, *e.g.* a clear assessment focus, measuring tools, control factors, duration and sampling size: (1) a focus on measuring the HBE characteristics, *e.g.* amount of daylight received; AND (2) a focus on measuring impacts, *e.g.* amount of analgesic medication taken.

The evaluation of these 305 papers was carefully carried out. Literature review papers were evaluated on the basis of findings and research trends that were identified. For example, it is quite consistent in the reviews that arts interventions are perceived to have a positive impact on health and wellbeing (Daykin, Byrne, Soteriou, & O'Connor, 2008; Moss, Donnellan, & O'Neill, 2012; Wilson, Bungay, Munn-Giddings, & Boyce, 2016). However, all reviews have a different focus. Daykin et al. (2008) reviewed the impact of art on mental health; Moss et al. (2012) reviewed the methodology applied in this area; while Wilson et al. (2016) reviewed it from the staff point of view. They also addressed the methodological challenges for future studies: evaluating complex interventions (Daykin et al., 2008); measuring receptive engagement (Moss et al., 2012); and combining diverse qualitative and quantitative approaches (Wilson et al., 2016).

The evaluation of empirical studies focused on both the research methods and findings. Studies with a higher level of academic rigour were selected. For example, both Hansen, Lund, and Smith-Sivertsen (1998) and Walch et al. (2005) concluded that daylight has a positive impact on health. However, Hansen et al. (1998) was a self-report survey, while Walch et al. (2005) was a quasi-experiment-controlled clinical trial. In this case, Walch et al. was reviewed in detail. Also, special attention was given to those with conflicting results. For example, the hospital fatality rate was found to be a statistically significant negative association with the volume (size) of the intensive care unit (ICU) (Glance, Li, Osler, Dick, & Mukamel, 2006; Peelen et al., 2007), while Jones and Rowan (1995) concluded that no association was found. In this case, both results were analysed for future study to pursue its positive characteristics regardless of the study design.

In total, of the 305 papers, 178 were excluded as their focus was outside the scope of this work and 127 were included. These 127 papers were used to identify the HBE characteristics and build the E-O-H framework. It is important to highlight that, as its true in any literature review that adopts a systematic approach, the search criteria used can affect the findings of the work. This issue has been mitigated through the detailed review of previously developed reviews of the literature in the area, which helps ensure that most relevant areas were included here.

## E-O-H framework development

The framework was initially defined on the basis of three design principles, as described in the next section. The framework was structured to include design principles, design parameters and sub-parameters, as exemplified in Figure 2. The 42 keywords (see step 4 above) acted as the starting point for the framework development, with terms used as potential (sub)-design parameters and classified under each of the three design principles. For example, 'light', 'ventilation', 'air quality', 'noise' and 'temperature' were classified under 'comfortable physical

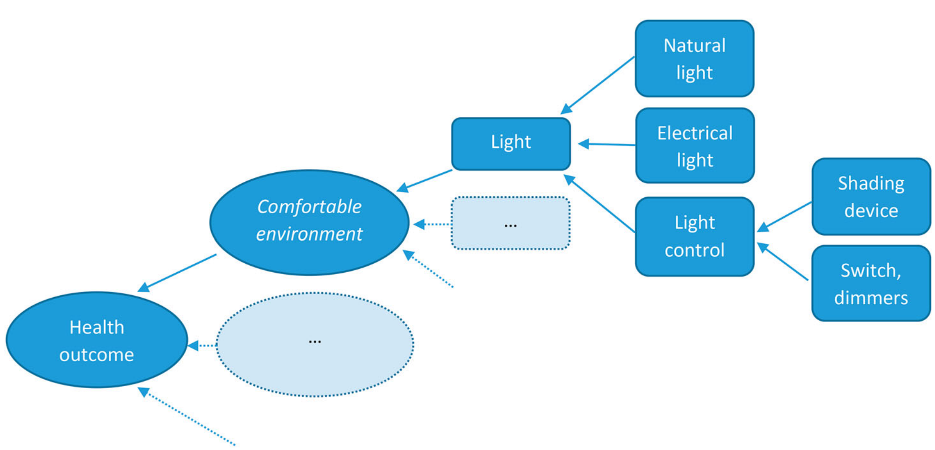


**Figure 2.** Structure of the holistic framework using 'light' as an example.

environment' (visually, acoustically, thermally). In this way, the E-O-H framework was developed in its preliminary form.

Through a process of reviewing the potential (sub)-design parameters and classifying the HBE characteristics identified in the literature into the framework (steps 4–6), the E-O-H framework gradually emerged. Furthermore, the existing evidence was organized in a tabular format; the results are presented in Tables 2–5.

The research was completed in June 2017. The final conceptual framework includes three design principles, 10 parameters and 31 sub-parameters. A total of 127 papers (59 review papers and 68 empirical studies) published in peered-reviewed journals, written in English, were included in this research.

## Results

### *Preliminary conceptual framework*

In order to consolidate the state of the art, researchers have explored the development of models to describe building design features that influence health outcomes (*e.g.* Elf, Nordin, Wijk, & McKee, 2017; Codinhoto, Tzortzopoulos, Kagioglou, Aouad, & Cooper, 2009; Ulrich, Berry, Quan, & Parish, 2010; Durmisevic & Ciftcioglu, 2010; Haq & Luo, 2012; Rashid, 2015). The purpose of these models is varied and influenced by diverse disciplinary foundations. However, scarce research has been undertaken to articulate a framework to evaluate HBE aspects holistically. Where evaluations are present, these have included one of two measurement aspects at best, with no clear theoretical underpinning.

Zeisel et al. (2003) focused on the holistic impact of care facilities on Alzheimer's patients. They proposed an *environment–behaviour factors* model to identify physical environment factors that influence behavioural and other health characteristics of residents with Alzheimer's disease in nursing homes. The authors identified environment–behavioural influences which included, for example, the degree of privacy and personalization, the amount of variability in common spaces, and links with aggression.

Barrett, Zhang, Moffat, and Kobbacy's (2013) research on the impact of building design on pupils' learning adopted Zeisel et al.'s (2003) work in proposing the *environment–human-performance* model. In their study, Barrett and Barrett (2010) started from the notion that the effect of the built environment on users is experienced via multiple sensory inputs in particular spaces, which are resolved in the human brain. The authors argue that the broad structuring of the brain's function can be used to drive the selection and organization of the environmental factors to be considered. The authors' environment–human-performance model takes a holistic perspective of the multi-sensory impacts of the built environment, which is operationalized via design principles, parameters and indicators. Barrett, Davies, Zhang, and Barrett (2015) provide evidence of the suitability of the framework in the context of primary school design, and conclude that classroom design could explain 16% of the variation in pupils' academic progress.

Following from the conceptual approaches of Zeisel et al. (2003) and Barrett and Barrett (2010), we propose a preliminary conceptual framework entitled environment–occupant–health (E-O-H). This framework incorporates three design principles:

- comfortable environment: to ensure the provision of continuous comfort, physiologically and psychologically, for occupants
- well-functioning healing space: any healthcare building has its own priorities and design features that focus on functionality, supporting diagnosis and/or treatment processes and promoting staff efficiency
- relaxing atmosphere: healthcare environments can be stressful, hence appropriate sensory stimulation for given situations in spaces can strengthen the positive (and/or weaken the negative) impacts

The term 'holistic' refers to the fact that the framework supports the consideration of the interactive effects of various HBE factors. In reality, these factors are interrelated. For example, maintaining an appropriate lighting level provides a *comfortable environment* (not too bright, *e.g.* glare, or too dull). An appropriate lighting level is also essential to ensure a *well-functioning space* (safety) in terms of minimizing medical errors. Furthermore, it affects the perception of a coloured display and/or wayfinding sign, which are efficient in alleviating stress levels (*relaxing atmosphere*). A further example includes achieving a good-quality sleep, which is about not only a quiet ward (*comfortable environment*) but also ergonomic beds (*well-functioning space*). Hence, it is important that HBE characteristics are considered in relation to each other and not in isolation, hence the need for a holistic approach.

This is also important as most previous studies have explored one single HBE factor and its impact on one single health outcome, without considering the important interplay between diverse HBE factors. The E-O-H proposed assumes that the negative impact of one HBE characteristic is sufficient to negate the benefits from the others. It also assumes that the achievement of good design characteristics can be cumulative, and no single characteristic is sufficient to achieve the full potential health benefits.

The identification of HBE characteristics described in the extant literature was used to develop the framework further, discussed below.

## HBE characteristics identified

Table 2 summarizes the HBE characteristics identified in the literature. The relevant studies can be traced in two ways: one is from the review papers that focus specifically on the impact of a particular design (sub)-parameter (*e.g.* natural light, noise), the other from the integrated review papers presented in Table 1. Note that as Table 1 has integrated all relevant findings, the sub-design/design

**Table 2.** Healing built-environment (HBE) characteristics identified in previous studies.

| Design principle[a] | Design parameter[a] | Sub-design parameter[a] | Covered in previous integrated review papers (see Table 1) |
|---|---|---|---|
| Comfortable environment (Nimlyat & Kandar, 2015) | Light (Boyce, 2010) | Daylight (Beute & de Kort, 2014) | ABCDEFGHIJ |
| | | Electrical light (McColl & Veitch, 2001) | CDFGI |
| | Sound | Noise (Brown, Rutherford, & Crawford, 2015; Hsu, Ryherd, Waye, & Ackerman, 2012; Konkani & Oakley, 2012) | ACDFGHIJ |
| | Temperature | Temperature (Khodakarami & Nasrollahi, 2012) | CEI |
| | Air quality (Sundell, 2004) | Air quality (Jones, 1999) | DEFG |
| | | Ventilation (Li et al., 2007; Sundell et al., 2011; Yau, Chandrasegaran, & Badarudin, 2011) | CFGI |
| Well-functioning healing space | Safety (Joseph & Rashid, 2007) | Floor and furniture, fixtures and equipment (FF&E) surface (Lachance et al., 2017) | ACDEFG |
| | | Water supply | G |
| | | Ergonomics (Hignett & Masud, 2006; Xie & Carayon, 2015) | CDFG |
| | Flexibility | Size and volume (Brand et al., 2012; Halm, Lee, & Chassin, 2002) | – |
| | | Space layout (Papoulias, Csipke, Rose, McKellar, & Wykes, 2014; Rashid, 2015) | CDEI |
| | | Acuity-adaptable rooms (Bonuel & Cesario, 2013) | G |
| | | Seating layout | DGH |
| | Patient-centred care | Beds per room (Chaudhury et al., 2005; Van de Glind et al., 2007) | CEGI |
| | | Facility control | DGJ |
| | | Social support (Rashid, 2010) | CG |
| | | Privacy/surveillance | ADG |
| Relaxing atmosphere | Display | Signage (Devlin, 2014) | CDG |
| | | Colour (Elliot & Maier, 2014) | ACIJ |
| | | Art (Daykin et al., 2008; Moss et al., 2012; Wilson et al., 2016) | ACDEFGIJ |
| | Links to nature (Maller, Townsend, Pryor, Brown, & St Leger, 2006; Keniger, Gaston, Irvine, & Fuller, 2013; Annerstedt & Währborg, 2011) | Indoor greenery | B |
| | | Views to nature (Grinde& Patil, 2009; Velarde, Fry, & Tveit, 2007) | ACDGHIJ |
| | | Therapeutic garden (Soga, Gaston, & Yamaura, 2017) | ACDGI |
| | Multi-effect | Music (Daniel, 2016; Evans, 2002; Wakim, Smith, & Guinn, 2010) | ABCEHIJ |
| | | Natural sound (Iyendo, 2016) | A |
| | | Odour (Wolkoff & Nielsen, 2017) | EHI |

[a]Review papers that focus on the impact of a particular design parameter.

**Table 3.** Relationships between healing built environment (HBE) characteristics and health outcomes.

| | | Design parameters | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Comfortable environment | | | | Well-functioning healing space | | | Relaxing atmosphere | | |
| **Health outcomes** | | **Light** | **Sound** | **Temperature** | **Air quality** | **Safety** | **Flexibility** | **Patient-centred care** | **Display** | **Links to nature** | **Multi-effect** |
| **Physical outcome** | Body integrity | Walsh-Sukys et al. (2001) | Hagerman et al. (2005) | | Sundell et al. (2011) | Donald et al. (2000) | | Persson and Määttä (2012) | | Velarde et al. (2007) | |
| | Pain | Walch et al. (2005) | | | | | | | Diette et al. (2003) | Kline (2009) | Bernatzky et al. (2011) |
| | Infection | | | | Li et al. (2007) | Salgado et al. (2013) | | Ben-Abraham et al. (2002) | | | |
| **Psychological perception** | Stress (anxiety, relaxation) | Partonen and Lönnqvist (2000) | Morrison et al. (2003) | | | | Parker et al. (2012)[a] | Foss and Tenholder (1993) | Dijkstra et al. (2008) | Beukeboom et al. (2012) | Alvarsson et al. (2010) |
| | Depression | Lieverse et al. (2011) | | Hartig et al. (2007) | | | | | | | |
| | Disorientation | Hidayetoglu et al. (2012) | | | | | | | Lee et al. (2014) | | |
| **Life experience** | Satisfaction | | | Wagner et al. (2006) | | | Sjetne et al. (2007) | Jongerden et al. (2013) | | Park and Mattson (2008) | Cruise et al. (1997) |
| | Stay length | Choi et al. (2012) | Fife and Rappaport (1976) | | | | Goodney et al. (2003) | | | Ulrich (1984) | |
| | Sleep quality | Bernhofer et al. (2014) | Xie et al. (2009) | Okamoto-Mizuno and Tsuzuki (2010) | | | | Freedman et al.(1999) | | | Williamson (1992) |
| | Social interaction | Aan Het Rot et al. (2008) | | | | | Holahan (1972) | Van de Glind et al. (2008) | Suter and Baylin (2007) | | Dennis (2011) |
| | Mortality | Freedman et al. (2002) | | Gosling et al. (2009) | | | Halm et al. (2002) | | | | |
| | Medical errors and work efficiency[a] | Buchanan et al. (1991) | Ryherd et al. (2012) | | | Chaudhury et al. (2009) | Mahmood et al. (2011) | Maben et al. (2016) | Wilson et al. (2016) | | |

[a]Staff-focused study.

parameters were not strictly the same as those presented originally. For example, 'visual comfort' in Huisman, Morales, Van Hoof, and Kort (2012) was included under 'daylight' and 'electrical light'; and 'ceiling lifts' identified by Ulrich et al. (2008) were combined into 'ergonomics' in this research.

Previous research on the HBE has seen contributions from diverse disciplines, including building and environment, care and nursing, psychology, and medicine. However, there is clearly an imbalance in the research attention given to each HBE characteristic. Some characteristics, *e.g.* light, noise, single-bed patient rooms, have drawn much more attention in previous research than other design parameters.

## HBE impact on health outcomes

Outcome measures in HBE studies are usually categorized according to a specific group of users: patients, family, non-physician staff, physicians and the organization (Huisman et al., 2012; Schweitzer, Gilpin, & Frampton, 2004; Ulrich et al., 2010). The majority of extant empirical studies have focused on patient outcomes. Codinhoto et al. (2009) explored this further to group patient outcomes according to the impact of HBE on their mind or body physically, physiologically and psychologically. In the same study, the physiological impact was intentionally omitted because body temperature, blood pressure, heart rate *etc.* were normally measured to indicate infection, pain (physical outcome) and/or to explain the level of pressure and stress (psychological perception). Moreover, 'life experience' was added as the HBE would affect not only their physical outcome and immediate psychological perception, *e.g.* blood pressure, but also their perceptions when staying at the HBE over the long term, *e.g.* sleeping quality, recovery time.

The studies presented in Table 3 have a high level of evidence on a specific design parameter and its impact on specific health outcomes. Note that although staff-outcome research has drawn much attention recently, *e.g.* burnout, sick leave, only those that are directly associated with patients' health outcomes were included in this research.

It can be seen clearly that one design parameter can contribute to more than one specific health outcome, while one specific health outcome can be achieved by more than one design parameter up to a certain level. For example, certain scents have been linked to mood-enhancing properties (Lehrner, Eckersberger, Walla, Pötsch, & Deecke, 2000). Its practical application, however, has focused on safety in the first place (*e.g.* fragrance allergies) and ventilation rates. Thus, a link can be seen here with the issue of relaxing atmosphere (scent), well-functioning space (safety) and comfortable environment (air quality), stressing the holistic nature of the relationships between HBE characteristics and, hence, the need for holistic design solutions. Moreover, health outcome measures are complex and hard to define even when the study of impact is focused on one specific benefit. For example, the quality of sleep (experience) may be affected by the patients' physical (pain) and psychological (stress level) conditions.

## Overview of the research methods used on previous HBE research

The current evidence from HBE was developed using varying research methods, depending on each study's interests and targets. Even though previous research contributes to the understanding of the relationships between the HBE and health outcomes, there are still questions regarding methods. For instance, to single out one HBE factor among the whole environment is as challenging as it is to control other non-HBE factors (*e.g.* demographic information, health history, hospital management, care providers' skills).

Table 4 describes how the HBE characteristics were investigated and the methods used in quantitative studies. There are varied ways to assess the HBE: less/more (*e.g.* noise level, illuminance, beds per room); before/after (*e.g.* movement, refurbishment, layout changes) and with/without (*e.g.* music, view outside). Also, the measuring tools for the health outcomes adopted come from different disciplines.

Table 4 does not identify any method as the 'most suitable', since each study's purpose, target environment and level of usage varies considerably. However, the presented research designs could be helpful as a starting point in the development process when it comes to HBE assessment and the choices of data-collection instruments.

Furthermore, randomized controlled trials (RCTs) are considered rigorous, with credible data and, consequently, are commonly viewed as providing the highest quality of evidence (Evans, 2003). However, public health researchers have asserted that the real world is too context rich and chaotic for trials (Macintyre & Petticrew, 2000). There is a debate that the RCT is not an appropriate method in research on long-term healthcare settings, in part because of 'the virtual impossibility of randomly assigning individuals to different environmental/treatment interventions and controlling cross-site variations' (Calkins, 2009, p. 146). Nevertheless, there is increasing evidence of how environmental cues link to the physiological functions of the human body

**Table 4.** Methods used in selected quantitative studies.

| Design principle/ parameter | Sub-design parameter | Assessment | Measuring tool | Control factor | Duration of the fieldwork | Rooms/participants involved | Study design |
|---|---|---|---|---|---|---|---|
| Comfortable environment/ light | Daylight (Walch et al., 2005) | Intensity of sunlight in patient rooms | Postoperative analgesic medication use<br>Self-evaluation of psychological and pain measures before and after the discharge | Patients in 'dim' side; age, sex, day of discharge and history of analgesic medication use | 4 months | East and west patient rooms in one hospital/89 patients | Quasi-experiment-controlled clinical trial |
| | Electrical light (Buchanan et al., 1991) | Pharmacy with three illuminance levels | Prescription-dispensing error rate | Total prescriptions dispensed; observer impact | 21 consecutive weekdays (7 days per illuminance level) | One pharmacy in one hospital/10,000+ prescriptions from five pharmacists | Quasi-experiment |
| | Control (Walsh-Sukys et al., 2001) | Illuminance level and control of a modified neonatal intensive care unit | Safety (medication errors, intravenous infiltrates *etc.*)<br>Staff perception (self-evaluation survey) | Illuminance level of a controlled room<br>Patient characteristics, *e.g.* age, race, gender, weight | 6 months | Two patient rooms in one hospital/126 babies and 69 staff | Quasi-experiment |
| Comfortable environment/ sound | Noise (Hagerman et al., 2005) | Sound level after the refurbishment (changing from the sound-reflecting to -absorbing tiles) | Blood pressure (pulse amplitude, heart rate and heart rate variability)<br>Incidence of rehospitalization<br>Self-evaluation of the care quality, patient satisfaction | Sound level before the refurbishment<br>Physiological condition; age, gender *etc.* | 4 weeks | Two patient rooms in one hospital/94 patients | Quasi-experiment |
| Comfortable environment/ thermal | Temperature (Azizpour et al., 2013) | Temperature measured in 10 thermal zones | Self-evaluation of the physical strength and thermal perception | Gender, ages, days of hospitalization | 6 months | 83 wards in one hospital/933 patient respondents | Empirical quantitative study |
| Comfortable environment/air quality | Air quality (Nordström, Norbäck, & Akselsson, 1994) | Exhaust air flow, aerosols and volatile organic compounds | Self-evaluation sick building syndrome and perceived air quality | Two hospital units without steam air humidification | 4 months in winter | Four hospital units/104 hospital staff | Empirical longitudinal study |
| | Ventilation (Escombe et al., 2007) | Air exchange per hour using a $CO_2$ tracer | Airborne infection rate (estimated) | 12 mechanically ventilated patient rooms from three hospitals built post-2000 | 368 experiments | 70 naturally ventilated clinical rooms from eight hospitals/- | Experimental comparative study |
| Well-functioning space/safety | Floor surface (Donald et al., 2000) | Carpeted and vinyl floors; two physiotherapy modes | Incidence of falls and the change in strength | Age, gender, health status, *e.g.* mobility, foot problems | 9 months | Five bays in one hospital/54 patients | Randomized $2 \times 2$ controlled trial |
| | FF&E surface (Salgado et al., 2013) | Patient rooms with copper alloy surfaces | Hospital-acquired infection rate | Patient rooms without copper alloy surfaces | 1 year | 16 rooms in ICUs of three hospitals/650 admissions | Intention-to-treat randomized-control trial |
| | Ergonomics (Capezuti et al., 2008) | Bed and toilet height | Falls | Demographic, health history and treatment | - | Four nursing homes/263 nursing home residents | Retrospective observational study using secondary data |
| Well-functioning space/flexibility | Flexibility (Pati, Harvey, & Cason, 2008) | Inpatient care-unit design | Adaptability, convertibility and expandability | – | 3 months | Six hospitals/48 care givers | Semi-structured interview |
| | Size (Sjetne et al., 2007) | Hospital size with three levels (bed capacity) | Self-evaluation of the care quality | Gender, age, length of stay, admission mode, health status *etc.* | 2 years | 50 hospitals/21,445 patients | Cross-sectional survey |
| | Acuity-adaptable room (Hendrich, Fay, & Sorrells, 2004) | Before and after the move | Patient transfer, satisfaction levels and medical errors | – | 2–3 years data before/after the move | One hospital/– | Pre-post-comparative observational study |
| | Waiting area (Leather, Beale, Santos, Watts, & Lee, 2003) | Before and after the relocation of the waiting area | Interview of the environment, mood and physiological arousal | Demographic characteristics and health profiles | Around 12 minutes in each interview | Two waiting areas in one hospital/145 outpatients | Pre-post-comparative survey |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Nursing station (Parker et al., 2012) | One centralized and one decentralized nursing unit | Perceived stress scale and demand-control-support questionnaire | Gender, age, years of experience at the current unit | – | Two nursing units in one hospital/40 nurses | Cross-sectional survey |
| | Seating (Holahan, 1972) | Four seating patterns in the day room | Amount and quality of social interaction; non-social activity | – | 45 minutes in each session | One hospital/120 patients | Cross-sectional observational study |
| Well-functioning space/patient-centred care | Single-bed room (Simon, Maben, Murrells, & Griffiths, 2016) | Before and after the conversion from 10% to 100% single-patient room | Infection, falls, pressure ulcers and medication errors | 'Steady-state' and 'new-build' control hospitals | 3 years | Three wards in three hospital/- | Natural experiment with non-equivalent controls |
| | Social support (Erdeve et al., 2008) | Individual room implemented family-centred care | Rates of telephone consultations<br>Acute care visits<br>Rehospitalization rate | Rooms without family-centred care; infant or parental characteristics | 1 year | Two hospitals/60 preterm infants and 49 mothers | Quasi-experiment |
| Relaxing atmosphere/display | Signage (Rousek & Hallbeck, 2011) | Standardized healthcare pictograms | signage recognition and comprehension | Gender | – | Laboratory work/50 participants | Experimental survey |
| | Colour (Dijkstra et al., 2008) | Photograph of a hospital room with green and orange walls | Self-evaluation of the stress, arousal and cognitive appraisals | Photograph of a hospital room with white walls stimulus; screening ability | – | Laboratory work/133 participants | Two experimental surveys |
| | Art (Diette et al., 2003) | Nature scene murals and sound | Self-rating pain control | Patient rooms without nature scene murals and sound | 4 months | Endoscopy suite in one hospital/80 patients | Randomized controlled trial |
| Relaxing atmosphere/links to nature | Indoor greenery (Park & Mattson, 2008) | Patient rooms with indoor plants | Medicine usage, recovery of surgical patients and self-evaluation of stress | Patient rooms without indoor plants | 6 months | Rooms located on the same floor and the same side of the building/90 patients | Randomized clinical trial |
| | Window view (Raanaas, Patil, & Hartig, 2012) | Private bedroom with a panoramic view to natural surroundings | Self-perceived physical and mental health, subjective wellbeing, emotional states, use of the private bedroom and leisure activities | Private bedroom without a panoramic view to natural surroundings | 22 months | 52 rooms in a residential rehabilitation centre/278 patients | Longitudinal quasi-experiment |
| | Garden (Whitehouse et al., 2001) | Gardens in paediatric settings | Reducing stress, restoring hope and energy, and increasing satisfaction | – | 32 hours in 2 weeks | One garden in a hospital/200 garden visitors | Post-occupancy evaluation |
| Relaxing atmosphere/multi-effect | Music (Korhan, Khorshid, & Uyar, 2011) | Patients who received 60 minutes of music therapy | Physiological signs of anxiety: respiratory rates and systolic and diastolic blood pressures | Patients who did not receive 60 minutes of music therapy | 8 months | 60 patients | Controlled, experimental repeated measures |
| | Soundscape (Mackrill, Jennings, & Cain, 2014) | Hospital ward soundscape | Self-rated emotional and cognitive response | Three soundscape of hospital ward interventions | – | Sound laboratory/24 participants | Experimental survey |
| | Odour (Lehrner et al., 2000) | Waiting room with an ambient odour of orange | Self-evaluation of trait and state anxiety, and current pain, mood, alertness and calmness | Waiting room without an ambient odour of orange; gender | – | Two waiting areas/72 patients | Controlled, experimental survey |

**Table 5.** Healing built-environment (HBE) characteristics adapted from the existing literature.

| Design principle | Design parameter | Practical options | HBE characteristics that relate to the occupants' health benefits (with keywords in bold) |
|---|---|---|---|
| Comfortable environment | Light | Daylight | **Morning sunlight** reduces the length of hospitalization in depression. Patients have experienced less perceived stress, pain and took less analgesic medication when receiving **abundant daylight** |
| | | Electrical light | **High illuminance level** is associated with a significantly lower error rate in dispensing medicines. **Full-spectrum fluorescent lighting** has a positive impact on a wide variety of health outcomes |
| | | Control | Illuminance **control** (shading devices, switches, dimmers) for the **different type of visual tasks** and the **age of the users** will alleviate the patients' stress and give them a certain level of choices |
| | Sound | Material | High noise level results in negative physiological and psychological discomfort and bodily fatigue. **Sound-absorbing ceiling tiles** and panels are good for reducing the noise disturbance |
| | | Isolation | **Acoustic barriers** and/or **background music** can limit the noise transmission and overhearing of conversations between others |
| | | Control | **Control over the noise level, music and television** will alleviate the patients' stress and give them a certain level of choice |
| | Heat | Temperature | Important to reconcile the **different thermal requirement** by different occupants, especially those patients and caregivers who have to stay in one room for a long time compulsorily |
| | | Control | **Control over the temperature and air movement** (air-conditioning, thermostat, heater, electrical fan) will alleviate patients' stress and give them a certain level of choice |
| | Air quality | Ventilation | Reliable ventilation strategy will assist the **air movement and exchange rate** to control the infection and promote health and wellbeing |
| | | Air-filtering system | Ventilation with an **air filter/humidification** will assist cleanliness and maintenance, reducing infection and promoting the users' environmental satisfaction |
| Well-functioning space | FF&E[b] | Surface | **Carpets** reduce falls and resultant injuries, noise level. **Hard flooring materials** are easy for maintenance and cleaning. No clear consensus exists as to whether contamination of carpeting was associate with a significantly increased infection rate[a] |
| | | | **Vinyl-covered surface** is better than fabric ones (furniture and curtains) in terms of removing bacteria through routine disinfection |
| | | Water supply | **Clean water** supply system reduces the waterborne infection transmission with proper temperature and adequate pressure, and regular cleaning, disinfection and **good maintenance of point-of-use fixtures**, *e.g.* sinks, faucets, aerators, showers and toilets |
| | | Ergonomics | Slippery floors, inappropriate door openings, poor placement of rails and accessories, and incorrect toilet and furniture heights are related to falls incidents. **Ergonomic** chairs and desks, adjustable and movable furniture, equipment reduce falls, back pain, and increase the social interaction |
| | Flexibility | Size | **Large units** improve patient outcomes by increasing average volumes of activity by clinicians. **Small** ones have a better satisfaction level from patients[a] |
| | | Patient room | **Identical patient rooms** and equipment makes routine tasks simpler and decreases errors by staff. They also have **adequate spaces** for medication supply and communication, reducing the stress among staff and patients |
| | | Nursing station | **Decentralization** reduces the walking time, thus increases patient care time. A **centralized** nursing station has more social interactions, sense of team connection *etc.*[a] |
| | | Acuity-adaptable room | **Acuity-adaptable room model** contributes to improved patient safety, healing process, staff stress and effectiveness. However, further validation is needed from empirical research |
| | | Seating | Arranging **chairs around small tables** increases interaction and social support when compared with chairs positioned shoulder to shoulder |
| | | Family zone | Family zone provides an area where patients and families can be together and provide a certain level of **flexibility** for alternative activities |
| | | Staff zone | **Staff area** provides an opportunity for relaxation, replenishment, networking *etc.*, thus is believed to affect the efficiency of services |
| | Patient-centred care | Beds per room | **Single-bed patient room** has its advantages in noise control, high quality of sleep and the experience of privacy, but patients can also develop passive, isolation feelings and need more staff time. The benefit is not conclusive when compared with the **multi-patient rooms**[a] |
| | | Facility control | **Well-planned environment** that considers climate conditions with manual control of light, heat, noise, air movement *etc.* reduces the length of stay for hospitalized patients and overall satisfaction |
| | | Social support | **Social space** (*e.g.* family zone or spaces without specific or prescribed functions) provides an area where patients and their families can be together and accelerates recovery and improves emotional wellbeing as well as the quality of life of patients |
| Relaxing atmosphere | Display | Signage | Typography, colour, pictograms and icons can be used in order to offer as much information as needed for coding, navigation and way-finding. **Clear signage** will reduce disorientation and stress that help patients and staff feel in control of their surroundings |
| | | Colour | **Calming and restoring colours** (*e.g.* blues, greens and violet) are recommended for high-stress areas and also areas that require concentration and visual acuity. Colours in the patient rooms and corridors would mitigate isolation, as well as enhanced better way-finding |
| | | Art | **Art content**, *e.g.* blue waterscapes, green landscapes and nature scenes, provides a calming atmosphere and enhances positive emotions, pain endurance, physiological responses and promotes restoration, nurse–patient communication and attitude toward hospitalization |
| | Links to nature | Indoor greenery | **Indoor courtyards and atria with greenery** promote positive feelings such as increased pleasantness, calmness and reduced anxiety, anger or other negative emotions |
| | | Window view | **View of natural scenery** provides pleasant distractions, alleviates the patient's stress, shortens the recovery time from surgery, reduces pain-relief drugs administered, and is satisfying compared with those patients who are exposed to views of a brick wall |
| | | Garden | **Well-designed gardens with easy entry and sitting areas** provide calming and pleasant views of nature, which are effective and beneficial for stressed patients and staff |
| | Multi | Music | **Therapeutic music** decreases patients' stress and anxiety. It is essential to give patients and staff **control** over their music preferences as not all type of music can produce a desired calming effect |
| | | Odours | Exposure to ambient **odour of orange** in the waiting area has a relaxant effect that patients feel a lower state of anxiety, have a more positive mood and a higher level of calmness. Its application, however, has to focus on particular needs for given situations without increasing the risk for a certain group of people (*e.g.* fragrance allergies) and ventilation rates in general |

[a]A future study is needed to pursue its positive characteristics.
[b]FF&E = furniture, fixtures and equipment.

and, therefore, therapeutic outcomes (*e.g.* Sternberg, 2009; Walch et al., 2005; Park & Mattson, 2008).

### Final E-O-H framework

Based on Tables 2–4, the final E-O-H framework is presented, collating the HBE characteristics that could be used to assist future research in the evaluation of the HBE (Table 5).

Firstly, the provision of a comfortable environment plays a fundamental role, thermally, visually and acoustically. In general, building design needs to focus on basic individual needs, with special attention paid to the overall effect of each environment. Studies on a comfortable environment mainly focused on individual parameters, *e.g.* light exposure level (Bernhofer, Higgins, Daly, Burant, & Hornick, 2014), noise (Waye, Elmenhorst, Croy, & Pedersen, 2013), temperature (Azizpour et al., 2013) and ventilation rates (Maddalena et al., 2015). Quantitative measurements were undertaken in these studies; however, limited links were identified between the interactions of these design parameters and occupants' overall comfort and satisfaction. This has also been indicated by Nimlyat and Kandar (2015) who reviewed the indoor environmental quality in healthcare facilities.

Secondly, a comfortable environment is a necessary (but not sufficient) condition for occupants' health and wellbeing. Well-functioning spaces make sure that purpose-built buildings are designed to meet the occupants' needs. Researchers, in this case, are careful in terms of suggesting design implications. For example, the (dis)advantages of (de)centralized nursing unit layouts has to be discussed by staff and/or considered from the patients' point of view (Pati, Harvey, Redden, Summers, & Pati, 2015; Rashid, 2015); the optimal number of beds in a patient's room requires further studies (Chaudhury, Mahmood, & Valente, 2005; Van de Glind et al., 2007), while Yildirim and Yalcin (2016) discuss the benefits of single rooms. Studies indicated that using carpets, or other low-impact flooring solutions, did not show significant differences in reducing the risk of falls compared with a vinyl flooring (Hanger, 2017; Warren & Hanger, 2013); while Lachance et al.'s (2017) review concluded that compliant flooring was a promising strategy for preventing fall-related injuries. On the other hand, it is clear that ergonomic furniture, fixtures and equipment (FF&E), and anti-slip facilities are necessary to reduce falls, back pain and increase social interactions, and for safety reasons (Carayon, Xie, & Kianfar, 2014; Clarkson et al., 2004; Reiling et al., 2004).

A relaxing atmosphere has the potential to reduce anxiety and depression. Lack of pictures on the wall, background music and beautiful views outside will not necessarily result in a severe health compromise, but having them may promote a positive effect on occupants' clinical outcomes and wellbeing. Such design parameters have been subject to considerable evaluation in previous research; however, existing RCTs are usually small in terms of sampling size and location.

Finally, Harper et al. (2015) find that patients' level of anxiety was lowered when the waiting room had scent or music. However, waiting rooms with both scent and music were also found to be ineffective in reducing anxiety, which may highlight the need for an appropriate level of stimulation, neither under- nor over-stimulating (Fenko & Loock, 2014). Once more, this stresses the importance to explore further the complexity of the HBE from a holistic and dynamic perspective.

## Conclusions

The existing evidence on the relationship between HBE and health outcomes is growing rapidly. A number of literature reviews were carried out to evaluate and build a credible evidence base. Such reviews highlight the lack of an adequate method that integrates credible findings holistically to demonstrate the cumulative and interactive effects of various environmental aspects on occupants' wellbeing. This has been highlighted since 2010 by Durmisevic and Ciftcioglu (2010), Huisman et al. (2012), Salonen, Lahtinen, Lappalainen, and Reijula (2013) and Nimlyat and Kandar (2015). However, most of the current research still focuses on examining the effect of a specific HBE characteristic on a specific health outcome for a certain group of occupants. This happens because it is very challenging to identify and measure clearly complex many-to-many relationships in practice and because there is lack of appropriate frameworks to do so. It may not even be feasible to identify all possible interactions between HBE factors and health outcomes, which is an inherent limitation to all studies of this nature.

Despite the challenges in identifying and measuring such many-to-many relationships, it is extremely important that research moves towards understanding and unravelling such complexities. The holistic approach proposed in this paper aims to support a move towards this direction.

The holistic approach means that further research should engage with an understanding of the whole healthcare building (diverse HBE factors) and in how it influences people at different levels, *i.e.* physical, mental and emotional. Hence, it considers that people are multidimensional, and that healthcare buildings are also multidimensional. It also considers that one dimension can influence many others, directly or indirectly. Future

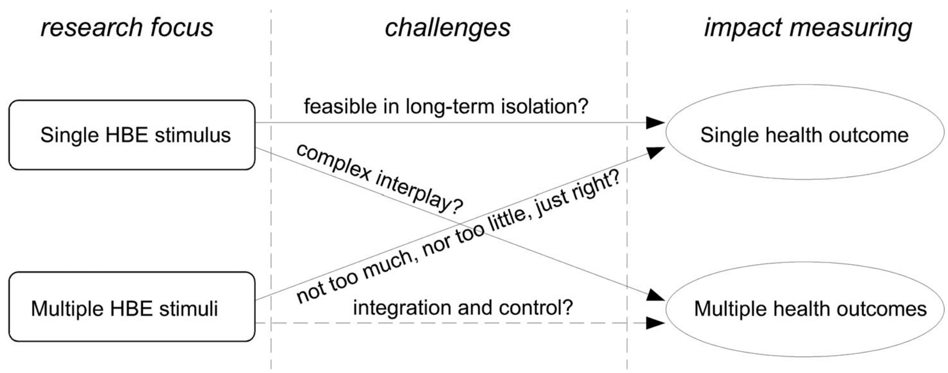


**Figure 3.** Research challenges in the healing built environment (HBE) impact on health outcomes.

developments towards HBE research need to adopt holistic approaches if research is to be of importance and value to practice.

This will enable the knowledge base to move forward, providing a better understanding of these complex and interactive relationships. This should further enable the future development of guidelines to support designers and healthcare planners about which HBE characteristics enable better health and wellbeing.

This table-based literature synthesis provides a contribution to the field by proposing a flexible and holistic E-O-H framework, which incorporates three design principles, informed by 10 parameters. The main observations drawn from the results of this work include:

- Theoretical/conceptual frameworks developed in previous studies were drawn from diverse research backgrounds for various purposes, and most lack practical validation. There is no consensus as to which is adequate to evaluate HBE and its impact on occupants' health outcomes in a holistic way.
- Existing studies on the impact of HBE on health outcomes are currently unbalanced. There is extensive research on parameters such as light, noise and single-bed patient rooms, whilst other parameters are under-researched. Therefore, there is a need to develop further rigorous studies on under-researched parameters to achieve a more comprehensive understanding (Table 2).
- Most of the existing research normally focuses on one design parameter and/or one health outcome. Therefore, when subtracted from its immediate context, the data collected and the results analysed in those studies may have been over-simplified, which provides a strong argument that a holistic study is necessary (Table 3).
- There is consensus that HBE characteristics play an important role in promoting the occupants' health outcomes. However, some applications need future study, *e.g.* the use of carpets or hard floor covering, a single-bed ward, a decentralized nursing station (Table 5). Furthermore, little is known about which health benefits can be directly attributed to one positive built environment factor.
- The extant research demonstrates that the HBE can have negative and positive impacts on users. There is a belief that if only a single HBE factor is at an unacceptable level (*e.g.* noise), the occupants' comfort will be severely compromised, independently of the quality of other factors.
- Quantitative measurements have been undertaken. However, the generated data are often from one or two spaces, which represent only a very small part of the whole healthcare building, covering a short period time and generally targeting a small sample of participants, either staff or patients (Table 4). Hence, there are methodological challenges to be addressed in future research on the HBE impact on health outcomes, as illustrated in Figure 3.

As a response to some of the issues highlighted above, this paper presents an E-O-H framework that provides a holistic perspective to integrate and evaluate different HBE characteristics. It provides a structure:

- to collate different HBE characteristics
- to categorize causal effects
- to support the definition of research methods to be applied in future studies to explore the impact of HBE on health outcomes
- to describe the HBE characteristics that could be used as the basis for collection and assessment in future holistic studies

It is important to note some limitations of this review. Papers not written in English were excluded. Some interesting HBE-related discussions from non-peer-reviewed papers were also excluded. For example, there are discussions around convenient car parks; and phone/wi-fi signals in the waiting areas and/or wards from hospitals self-made reports. These could be potentially important HBE factors, but they were intentionally omitted because no related work has been found in peer-reviewed papers.

This paper provides a state-of-the-art review of current research in the area, and also provides a framework for future research to improve the understanding of HBE in design-related fields. In doing so, it establishes directions for future research. The E-O-H framework needs to be tested and further developed through fieldwork.

The integrative tables presented are a key research result as these extend the existing knowledge through integration, and serve as a starting point for future studies, allowing the identification of built-environment characteristic and the measurement of their impacts on health outcomes in a holistic manner.

The E-O-H has the potential to be of interest to a range of professionals and academic researchers who work in planning, designing and constructing healthcare buildings. There is increasing interest in the evaluation of the effectiveness of healthcare buildings in promoting health for patients and staff, and the E-O-H framework offers a means to make more effective comparisons between differing design solutions. Also, it could provide a common language between clinicians, planners, designers and patients when a healthcare building/space is built or refurbished.

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