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Healing Environments: What Design Factors Really Matter According to Patients? An Exploratory Analysis

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Abstract

Objective: The main aim of this research was to identify the impact of design characteristics (DCs) of a patient room on self-reported patient well-being. **Background:** This knowledge enables the construction of healing environments focusing on DCs that maximize well-being. Six themes were identified in literature that create healing environments: *spatial comfort*, *safety and security*, *autonomy*, *sensory comfort*, *privacy*, and *social comfort*. We wondered what themes and associated DCs should be prioritized if needed to maximize well-being. **Method:** The physical environment of patient rooms in four hospital locations was measured and patients who stayed in these rooms were asked to evaluate the room design on abovementioned themes and its contribution to their well-being. We used a machine-learning technique and regression analysis to find relations between the physical environment of a patient room and patient well-being. **Results and Conclusions:** We found that spatial comfort, safety and security, autonomy, and associated DCs have the strongest ability to influence patient's self-reported well-being in a patient room. Privacy appears to have the smallest influence.

Keywords

evidence-based design, patient room design, machine learning, hierarchical multivariate regression, patient well-being

Introduction

The term healing environment is often used in healthcare settings. The exact meaning however or the characteristics that determine a healing environment is often unclear and subject to opinion. From a patient perspective, we consider a healing environment as one that has a proven positive influence on the healing process or psychological well-being of patients. An influential study of Ulrich (1984) on the contribution of a view on a natural environment on recovery of a cholecystectomy started the "healing environment" research to increase. Numerous aspects of the physical healthcare environment have been

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studied since. Although the methodological quality of some of this research can be questioned, six themes with associated design characteristics (DCs) can be identified that may contribute to a healing environment for patients (College Bouw Zorginstellingen, 2008): *spatial comfort*, *privacy*, *autonomy*, *sensory comfort*, *safety and security*, and *social comfort*.

Currently, it is unclear which themes and associated DCs have the strongest contribution in influencing patients' (psychological) well-being. This is because the influence of DCs is often investigated in isolation of other physical environmental aspects, for example, the effect of the view (Ulrich, 1984). The environment, however, is perceived in a holistic manner (Bitner, 1992), and an intervention that is effective in a certain environment may not be as effective in another environment. For instance, a nice view may be less important if there is an appealing interior design. The purpose of this research was to explore the question, while taking into account all themes, what theme(s) and associated DCs have the strongest impact on patient's self-reported well-being? In other words, if a hospital administration only has a limited budget in which themes should be invested first?

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Spatial Comfort

We use spatial comfort as a collective term for comfort provided by physical features and use of space in the environment. In general, the functional, personal, and social evaluation of a space determines feelings of comfort (Buttimer & Seamon, 1980; Sixsmith, 1986). A space is comfortable if it supports activities a person wants to execute in that space (functional evaluation), personal needs (personal evaluation), and envisaged social interaction (social evaluation). For a patient room, this means the room should be spacious enough, for example, to get in and out of bed, move around, and host company, and is there an opportunity to personalize the room. Other DCs that have been investigated are the interior design and views/access to nature. Interior design including the style and looks of the walls, flooring, ceiling, and furniture affect a patient's mood (Dijkstra, 2009), feelings of trust (Stienstra, 2005), and overall satisfaction (Harris, 2000; Swan, Richardson, & Hutton, 2003; Ulrich et al., 2008). Views on nature have pain and stress reducing effects (Malenbaum, Keefe, Williams, Ulrich, & Somers, 2008; Ulrich, 1984; Ulrich, Lundén, & Eltinge, 1993; van den Berg & Winsum-Westra, 2006). This can be a real view on nature, pictures with a nature theme, or access to nature (i.e., plants and patio). In sum, DCs associated with spatial comfort are room dimensions, space that can be personalized, interior design, and views and access to nature.

Privacy

We use the term privacy as the need for one's own territory and the ability to shut out information about others (Prevosth & van der Voordt, 2011). For patients, a lack of privacy, either visual or auditory, can lead to feelings of discomfort (van de Glind, de Roode, & Goossensen, 2007). Research suggests several DCs that affect privacy in the patient room. The most important one is the number of beds (Chaudhury, Mahmood, & Valente, 2005; Huisman, Morales, Van Hoof, & Kort, 2012; Ulrich et al., 2008; van de Glind et al., 2007). Single rooms seem to increase feelings of privacy, dignity, and overall satisfaction and improve sleep. Others DCs include type of bed partitions, lines of sight, use of sound absorbing materials, and places for private discussion (Barlas, Sama, Ward, & Lesser, 2001; Hagerman et al., 2005; Heerwagen & Heerwagen, 2007; Joseph & Ulrich, 2007). Studies on patient satisfaction also indicate the importance of sanitary privacy for patients and family members (Brown & Gallant, 2006; Conner & Nelson, 1999).

Autonomy

The term autonomy refers to the freedom to determine one's own actions and behavior or to experience control. Many procedures in hospitals indicate the dependency of patients on staff and lack of control over the unknown treatment (College Bouw Zorginstellingen, 2008; Douglas & Douglas, 2004; Stienstra, 2005). Lack of control is associated with stress, depression, high blood pressure, and weaker immune system (Devlin & Arneill, 2003; Ulrich, 1992). DCs associated with autonomy are the possibility to control the environment such as opening a window, adjusting lighting and temperature settings, closing the door, and shutting lines of sight.

Sensory Comfort

We use sensory comfort as a collective term for comfort provided by the environment on human senses, such as (day)light, fresh air, scent, temperature, and noise. In research especially (day)light, fresh air and noise levels are stressed (Gezondheidsraad, 2009; van den Bergh, 2005). Light regulates the circadian rhythm which regulates body temperature and sleep–wake rhythms (Turner, Van Someren, & Mainster, 2010). Appropriate lighting may reduce depression, length of stay, patient stress, and medical errors (Beauchemin & Hays, 1996; Benedetti, Colombo, Barbini, Campori, & Smeraldi, 2001; Buchanan, Barker, Gibson, Jiang, & Pearson, 1991; Federman et al., 2000; Martiny, Lunde, Undén, Dam, & Bech, 2005). Music may be stress reducing in hospital settings (Diette, Lechtzin, Haponik, Devrotes, & Rubin, 2003), but high noise levels are associated with cause of awakenings and poor sleep (Gabor et al., 2003; Tegnestedt et al., 2013; Ulrich et al., 2008). Number of beds is also an important DC associated with reduced noise levels (Chaudhury et al., 2005; Gabor et al., 2003; Ulrich et al., 2008). Other DCs are sound absorbing materials used on walls and ceilings (Ulrich et al., 2008). In sum, windows, appropriate lighting and temperature settings, number of beds, sound absorbing materials, and ventilation type (fresh air) are DCs associated with sensory comfort.

Safety and Security

Safety and security refers to the patient's perception of these factors and not to, for instance, the risk of acquiring hospital-related infections (Bartley, Olmsted, & Haas, 2010; Dettenkofer et al., 2004), although this risk is significant and there are numerous DCs that seem to influence it. Perceived safety in general is influenced by the feelings of prospect, refuge, and escape (Appleton, 1975; Fisher & Nasar, 1992). In the context of a patient room, prospect seems associated with overview, lighting, and lines of sight (can danger be detected), refuge can be translated in safe storage of belongings (can valuables be hided) and escape can be associated with the observation of staff and the ability to call support (can I be supported in case of emergency). Number of beds is also associated with perceived safety, as other patients may offer support (Ehrlander, Ali, & Chretien, 2009; van der Voordt, Lüthi, & Niclaes, 1994).

Social Comfort

Social comfort refers to emotional, informative, and instrumental support by friends, family, staff, and other patients (Kahn & Antonucci, 1980; Kaunonen, Tarkka, Paunonen, & Laippala, 1999; Koivula, Paunonen-Ilmonen, Tarkka, Tarkka, & Laippala, 2002; Prevosth & van der Voordt, 2011). Social support seems to improve patients' physiological well-being (Kaunonen et al., 1999; Koivula et al., 2002). The need for social support increases in stressful events such as admission to a hospital. Regrettably, one's social network tends to decrease during hospitalization (Tarkka, Paavilainen, Lehti, & Astedt-Kurki, 2003). Number of beds seems to affect the quality of the communication with staff (van de Glind, van Dulmen, & Goossensen, 2008). The interior design also impacts social comfort by the use of carpeting and placement of chairs around tables (Ulrich et al., 2008). Several forms of media, television, radio, and Internet also provide distraction for patients in a positive but sometimes also in a negative way (disturbing sleep; Lee & Lin, 2007).

Current Research

To answer our research question, we physically measured different patient rooms and asked patients who stayed in these rooms to what extent the room contributed to their well-being and how they perceived different aspects of their rooms. We used a machine-learning technique to find the effect of the DCs of the patient room on patient evaluations. This technique enables to calculate weights between physical design inputs and subjective patient evaluations by taking all physical characteristics and patient evaluations simultaneously into account. By analyzing these weights, the hierarchical impact of themes and DCs on patient well-being can be assessed. We used machine learning as unlike more traditional regression techniques, this technique allows us to take many variables of different scale levels into account simultaneously, without specifying an assumed type of relation (linear, nonlinear, etc.). Since this technique, to our knowledge, was never applied to survey outcomes, we also used regression techniques to better understand the machine-learning findings based on the patient evaluations only (as the many DCs could not be included in the regression model). Due to these underlying technique differences, the outcomes of the two techniques cannot simply be compared. Nevertheless, we believe that combining these two techniques generates interesting insights in the hierarchical impact of DCs on self-reported patient well-being.

We used a machine-learning technique to find the effect of the DCs of the patient room on patient evaluations.

We limited the scope of our research to the context of the patient room, as we first wanted to test the machine-learning technique in a limited scope before analyzing the effects of a hospital as a whole. The scope was also chosen because we believe that the patient room is the environment that patients are most exposed to when staying in a hospital. Therefore, upgrading the patient room to become a healing environment has a great potential to benefit patients.

Method

Participants

Although, for this research, patients were recruited in four hospital locations in the Netherlands, the majority of them were recruited at one location. The criteria for patients to participate in this research included a stay of 2 or more days in their patient rooms, at least 18 years old, and able to read and answer the Dutch questionnaire. Three hundred and seventy-nine (379) patients in 48 patient rooms filled in a questionnaire to measure how the environment was perceived (mean number of patients per room 8.6 $\pm$ 8.2 patients). Of the total sample, 52% were female and 78% were older than 45 (of which 36% were older than 65). The majority (77%) of the sample had a low level of education (primary school or secondary education). Table 1 provides an overview of the patient sample per patient room and location. Patients were included from the departments of traumatology, orthopedics, cardiology, oncology, nephrology, internal medicine, and endoscopy. The reason for admission was not recorded, in order to receive the approval for the research from the ethics committee of the main location. As an alternative, we recorded the perceived severity of the illness. Thirty-eight percent of the patients reported a neutral score in between very severe and not severe at all, 32% scored not severe to not severe at all, and 31% scored severe to very severe.

Survey

A pencil-and-paper survey was used to measure how the patient room and its direct vicinity was perceived and to what extent the patient room contributed to patients' well-being. The questionnaire contained the following items:

- Questions (2) on the mental state of patients to be indicated on a 5-point scale (based on the affect grid of Russell, Weiss, and Mendelsohn, 1989).
- Statements (103) on the perception of the physical environment. The statements were subdivided into statements about the themes: spatial comfort, privacy, autonomy, sensory comfort, safety and security, and social comfort. Example statements are "To what extent: is there enough space in my room to comfortably get in or out of the bed (spatial comfort), is the lighting/

Table 1. Overview Patient Sample Per Hospital Room.

Hospital Location	Room	*n*
A	201	6
	202	3
	203	8
	204	2
	205	2
	206	3
	208	2
B	101	7
	103	20
	104	1
	105	5
	106	3
	107	6
	109	8
	114	1
	116	1
	204	3
	205	2
	206	19
	208	7
	210	8
	212	19
	213	2
	215	1
	303	10
	305	28
	306	22
	307	5
	309	10
	311	23
	314	3
	316	2
	402	12
	403	17
	404	33
	406	11
	408	13
	410	25
	411	3
C	25	3
	26	6
D	209	3
	211	6
	219	5
Total		379

temperature/noise comfortable (sensory comfort), do you feel safe in your room, can you safely store your belongings (safety and security). Patients had to answer these statements on a 5-point Likert-type scale ranging from, for example, comfortable–uncomfortable and agree–disagree.

- An open question after every theme for any remarks.
- Scores (scale 1–10) for the contribution of the patient room to well-being and the contribution of the department as a whole.
- Questions on the background of the patients such as gender, age, education level, and perceived severity of the illness.

A research assistant indicated the department and room the participant was in, bed position, and the date of submission. The questionnaires were filled in between September 2012 and July 2014.

Survey procedure. A research assistant was trained to provide patients with the questionnaire. Patients were informed about the research by an information letter. Patients participated voluntarily. Every patient who participated signed an informed consent up front. Patients filled in the questionnaire alone or with the support of the research assistant. The patients had no time restrictions to hand over the questionnaire. The questionnaire could be handed over to the research assistant or put in a box at the department. The data were processed anonymously.

Patient Room Physical Measurements

Based on the identified themes and associated DCs in literature, physical DCs of the patient room and its direct vicinity that could possibly influence the themes were measured. Hundred and thirty-nine characteristics were determined per individual room and bed position. Examples of DCs are room dimensions, type of view, interior (spatial comfort), number of beds, personal storage space and volume (privacy), type of control over window/lighting/ventilation (autonomy), distance to reception/communication facilities, and number of chairs (social comfort).

Physical measurement procedure. Rooms were measured before or after the stay of the patients. The data set consisted of single- and multibed rooms (2, 3, and 4 persons). An external trained research assistant conducted the physical measurements

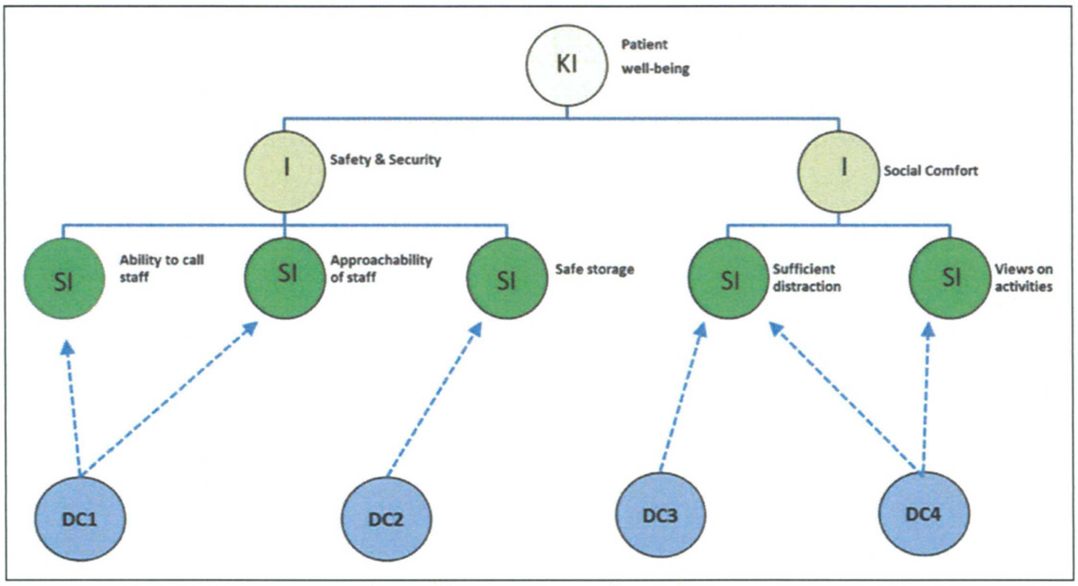

Figure 1. Simplified part of hierarchical back propagation model.

using a camera to capture the visual input of patients such as the interior design and view, which was coded afterward; a surface area measuring device to measure the length, width, height, and square meters or distances to locations. Other items were measured by assessing whether aspects were present or not: possibility to open a window (yes, no), possibility to store possessions safely (yes, no), and so on. Ambient factors such as lighting levels, temperature, and decibels were not taken into account, since a direct link with these levels at the time the questionnaire was filled in could not be made.

Analysis

Model description. To use machine learning for analyzing the hierarchical impact of the DCs on patient's well-being, we developed a hierarchical model that connects the DCs to the patient well-being themes and indirectly to the overall self-reported patient well-being score. These linkages were based on available literature. In the model, the key indicator (KI) patient well-being was connected to the different theme indicators (I; spatial comfort, autonomy, sensory comfort, safety and security, privacy, and social comfort). These theme indicators were then connected to subindicators (SIs) and DCs. Figure 1 provides an example of this hierarchical model. It shows a simplified part of the model for the theme indicators safety and security and social comfort. Safety and security is among others, dependent on the perception of the ability to call staff, approachability of staff, and the safe storage of belongings. We measured the performance of all these indicators (green) in the survey. The indicators at the lowest level of the hierarchical model were connected to specific DCs (blue). In this example, Design Characteristic 1 (DC1) could be about the distance of a nurse station to the patient room. This characteristic may have an effect on the approachability of staff, and the extent to which staff is able to react to patient calls (impacting the patients' perception on the ability to call staff). As the figure shows, DCs can have more than one connection in the model. In this way, all DCs on room level were linked to SIs of patient well-being.

We assumed that each DC has a certain effect on the connected SI and that each SI has a certain effect on the theme I above that SI and indirectly to the KI. To describe the effect on an indicator (SI, I, or KI), we used a function that shows that the valuation of that indicator is a weighted average of the valuations of its SIs or DCs (these are I for KI, SI for I, and DC for SI). This effect is expressed by a weight ω_i. With the help of these weights, the values of DCs or SIs, and the formula below, a predicted valuation of an indicator ($Y_{\text{KI,I, and SI}}$) can be calculated. The formula that describes the relation between DCs or SIs (SI and I) and indicators directly above (SI, I, or KI) is:

$$Y_{SI} = \frac{1}{1 + e^{-(\omega_1 DC_1 + \omega_2 DC_2 + \omega_3 DC_3 \ldots + \omega_n DC_n + \theta)}},$$

or

$$Y_{I} = \frac{1}{1 + e^{-(\omega_1 SI_1 + \omega_2 SI_2 + \omega_3 SI_3 \ldots + \omega_n SI_n + \theta)}},$$

or

$$Y_{KI} = \frac{1}{1 + e^{-(\omega_1 I_1 + \omega_2 I_2 + \omega_3 I_3 \ldots + \omega_n SI_n + \theta)}},$$

where Y is the valuation of an indicator. ω_i represents the weights connecting DCs to SIs, SIs to (theme) indicators (Is), or (theme) indicators (Is) to the KI. DC_i, I_i, and SI_i depict the measured value of the DC (theme) indicator or SI, respectively. θ is a constant. This formula follows from the function $\frac{1}{1+e^{-x}}$ often used in the machine-learning techniques (Sibi, Allwyn Jones, & Siddarth, 2013). The idea behind the formula is that an indicator is affected by one or multiple subindicators and/or DCs. The more extreme this joint contribution is (either very high or very low), the less the relative effect a change in the input values (SIs and or DCs) has on the predicted value of that indicator. To find the value of all defined weights between the DCs, SIs, and Is, the model was trained. The value of the weights corresponds with the relative contribution of an SI or DC to an indicator higher in the hierarchy. By analyzing the weights and error terms of the weights, which indicate how well the weight could be estimated based on the data, the hierarchical impact of DCs on patient well-being was identified. Thus, training of the model is key to derive at the best fitting weight parameters ω_i. This is explained in the next section.

Training the model. Training the model should not be confused with the validation of the model. Training the model means finding the weights (ω_i) to be able to predict indicator outcomes, based on the given data set. Validation would be to enter new cases, not included in the training data set, and validate whether the predicted patient evaluations provided by the trained model are close to the real observed patient evaluations of these new cases. In this research, we only trained the model and looked at the error margin, which indicates how well the model could be trained and predict based on the current data set.

To train our model, we used a machine-learning technique called back propagation (BP). This is a common method of training neural networks. BP is a form of supervised learning that is able to infer a (parameterized) function from labeled training data (Mehryar Mohri, 2012). By labeled training data, we mean the combination of input data and the desired output. In our case, the input data consisted of all DCs of the patient rooms with their corresponding values (from the physical measurement) and valuation of the indicators (from the patient survey) in the hierarchical model, hereafter referred to as BP model. Training (or fitting) the model means finding the weights between the connections in the model (ω_i) that lead to the lowest average error margin between predicted and real indicator values. To find these weights, an iterative process is used with the following steps:

0) Generate random values for all ω_i's.
1) Select a patient (from the survey data).
2) Find the corresponding DC values (from the physical measurement).
3) Fill in these characteristics and predict the value of an indicator or the KI.
4) Find the corresponding real valuations of the patient.
5) Is prediction > valuation?
   a) YES: decrease the value of the ω's according to the difference between prediction and valuation.
   b) NO: increase the value of the ω's according to the difference between prediction and valuation.
6) Go back to 1.

Step 5 uses a gradient descend method to derive "the right direction." The exact update rule for adapting the parameters can be easily derived by calculating the derivative of the model functions (Rojas, 1996) and is therefore omitted here. This iterative process is repeated until the progress stagnates and hence a (local) optimum is found. For our model, this process was repeated 50,000 times to get the best fitting weights. Indicator data of all patients ($N = 379$) and 139 DCs of each room ($n = 48$) were used to train the model.

Each time the algorithm runs through the iterative process, a certain part of the BP model is evaluated. This part is chosen randomly. This means the BP model is not integrally trained. The reason is because the data on the KI and SIs are the results of questionnaires filled in by patients and therefore are most likely related but not coherent.

BP analysis. The results of the BP analysis show for each connection in the BP model, what the quantified weight is, indicating the size of the effect on the indicator above. Large weights indicate a large effect on the indicator; small weights indicate a small effect on the indicator. By analyzing the weights, the relative importance of DCs and indicators were determined.

The BP model also generates an average error margin per indicator, which indicates how well an indicator is predicted by its SIs or DCs directly below. We considered error margins above 1 as high. This means that the prediction on a scale from 1 to 5 is 1 point or more off. High error margins indicate that the indicator could not be well predicted either because the wrong connections were made or because the evaluation of individual persons about the same environment differs too much to make a good general prediction.

Hierarchical Multivariate Regression Analysis

To analyze the hierarchical impact of theme indicators on patient well-being, we ran a hierarchical multivariate regression with the patient well-being score as the dependent variable and the theme indicators as independent variable. One item in the questionnaire was used as a theme-indicator score. For instance, the score on the statement "to what extent do you feel safe in your room" was used as general safety and security score, representing the theme safety and security. The hierarchical multivariate regression included two models. In the first model, we entered the dummies for the different hospital locations. In the second model, we included the independent variables. In this way, the effects of the independent variables were controlled for location effects, indicating that the effects found apply in general, independent of the context of a location. We used SPSS, Version 22, to carry out the analysis.

Since 1 item in the questionnaire might not represent a theme, we also conducted a factor analysis (principal component analysis with varimax rotation). In this way, all room-level statements in the questionnaire were reduced to meaningful design factors consisting of multiple items. Items with a factor load >.3 were assigned to the respective factor. Items that loaded on more than one factor were logically assigned based on content. After composing the factors, Cronbach's αs were calculated for the factors consisting of more than 3 items to determine internal validity. All factors had an α of .7 or higher and were identified as design factors. We also carried out a hierarchical multivariate regression with patient well-being as dependent variable and the identified design factors as independent factor to identify whether these results corroborate too with the BP analysis.

To better understand the outcome of the BP analysis, we carried out hierarchical multivariate regressions based on the BP model structure. In this way, the model structure of patient well-being and the different themes were validated. To validate the model of the themes, we carried out hierarchical multivariate regressions with the theme indicator as dependent variable and all subindictors as independent variables. Only the significant predictors are reported. Please note that only the indicators (survey answers) could be used in this analysis not the data on the physical DCs.

Results

In this section, we report the results of the BP and regression analyses. We follow the structure of the BP model. We start discussing the results at

Table 2. Theme Predictors of Patient Well-Being.

Patient Well-Being (Error Margin = .42)						
Themes	Safety and Security	Spatial Comfort	Autonomy	Sensory Comfort	Social Comfort	Privacy
Weight	0.131	0.126	0.125	0.124	0.112	0.108

Table 3. Effects on Patient Well-Being.

Patient Well-Being ($r^2 = .35$)						
	Spatial Comfort	Autonomy	Safety and Security	Social Comfort	Sensory Comfort	Privacy
β	.328	.212	.142	.126		
p	<.001	<.001	.002	.003	*ns*	*ns*

Note. ns = not significant.

the top of the model, where the six themes are connected to the overall self-reported patient well-being score. Subsequently, we zoom into every theme model to understand the important indicators and DCs per theme and also to better understand the results in the top of the model. For each part in the model, we first report the results of the BP analysis, accordingly the regression analysis results are reported and interpreted.

Patient Well-Being

BP analysis results. The results of the BP analysis where the themes are connected to the overall self-reported patient well-being score are shown in Table 2. In the topline, the error margin is shown. This indicates that when patient well-being is predicted based on the score of the different underlying themes, the prediction differs 0.42 points on average (on a scale from 1 to 5). Per theme, the calculated weight is shown. In the table, they are ranked from largest effect (left) to smallest effect (right). This applies to all tables presented in the BP analysis results. It should be noted that the influence of underlying indicators and DCs on the theme is taken into account. Thus, although we only present the indicators directly below the indicator under review, the model structure that lays beneath impacts the results.

Regression analysis results. The results of the hierarchical multivariate regression analysis with the overall well-being score as dependent variable and the general score on the theme indicators (indicated by 1 item in the questionnaire) as independent variables are shown in Table 3. The topline shows the explained variance. In this case, 35% of the variance in the self-reported well-being score is explained by the theme scores ($p < .001$). Per theme, the standardized β and *p* value are reported of predictors. The standardized βs indicate the relative importance of the significant predictors. In the table, predictors are ranked from largest effect (left) to smallest effect (right). The *p* value indicates whether the SI has a significant contribution to the indicator in the topline ($p < .05$). The effect is controlled for location effects, as the different locations were also included in the regression model. This applies to all regression analysis results. The difference in the BP analysis is that underlying indicators and DCs are not taken into account in the regression analysis. However, in the theme analysis, it is investigated to what extent the included underlying indicators explain the general theme score. It provides insights how well the general theme indicator score represents the SIs. In this way, the results of the top can be interpreted based on the theme analysis.

The results of both analyses show that the top three themes corroborate, although not in the same order. Spatial comfort, safety and security, and autonomy have stronger effects on self-reported well-being than social comfort, sensory

Table 4. Identified Design Factors Based on PCA.

Design Factors	# Items	Cronbach's α	Theme
Interior design	16	.96	Spatial comfort
Indoor climate	7	.88	Sensory comfort
Spacing	7	.87	Spatial comfort
Perceived safety	3	.75	Safety and security
Safety support	6	.83	Safety and security
Interior view	3	.78	Spatial comfort
Outside view	3	.83	Spatial comfort
Privacy control	5	.88	Autonomy/ privacy
Communication	3	.74	Social comfort
Noise	2	NA	Sensory comfort
(Day) lighting control	5	.72	Autonomy/ sensory comfort
Temperature control	3	.68	Autonomy
Unwanted views	2	NA	Privacy
Hygiene	3	.75	Sensory comfort/ spatial comfort

Note. PCA = principal component analysis; N/A = not applicable.

Table 5. Predictors of Patient Well-Being.

	Patient Well-Being (r^2 = .45)		
	Spacing	Hygiene	Communication
β	.208	.183	.100
p	.001	.004	.040

Table 6. Effects on Safety and Security.

Safety and Security (Error Margin = .70)				
Indicator	Restriction of Unauthorized Persons	Lighting	Storing Space	Availability of Personnel
Weight	.388	.355	.272	.259

comfort, and privacy. According to the regression analysis, sensory comfort and privacy are not significant predictors of patient well-being.

Factor analysis results. We also conducted a factor analysis as explained in the method section. Table 4 shows the identified design factors. Of every identified factor, the number of included items, the Cronbach's α, and the corresponding theme in the BP model are reported. Table 5 shows the results of the hierarchical multivariate regression.

The table shows that 45% of the variance in self-reported well-being is explained by the design factors. Spacing (e.g., "there is enough space to go in and out of bed, there is enough space to store belongings, and the room is comfortable"), hygiene (e.g., "the interior of the room is well cared for and to what extent do you consider the room clean"), and communication (e.g., items on the possibility of communicating with family, friends, or other patients, at department level) are the generic significant predictors. These results indicate that indicators of the themes spatial comfort (spacing and hygiene), sensory comfort (hygiene), and social comfort (communication) are the strongest predictors of patient well-being. Interestingly, no safety and security or autonomy indicators were included in significant design factors contributing to patient well-being.

Safety and Security

The results of the BP analysis for the safety and security model are shown in Table 6. The results of the hierarchical multivariate regression analysis are shown in Table 7.

The error margin in Table 6 shows that this theme could be best predicted based on the underlying indicators, as it has the lowest error margin compared with the other themes. Both analyses show that perceptions of whether the room is restricted for unauthorized persons are strong predictor of feelings of safety and security. A safe storage place, however, is the strongest predictor in the regression analysis; whereas in the BP analysis, it comes after the controllability of lighting. The difference in this hierarchy may be explained by the fact that the BP model optimizes for patient well-being. Therefore, all SIs are also weighted based on their relation to well-being and not just to safety and security as the regression analysis does. This indicates that a safe storage

Table 7. Significant Predictors of Safety and Security.

	Safety and Security ($r^2 = .32$)			
Indicator	Safe Storage Space	Restriction for Unauthorized Persons	Ability to Quickly Call Personnel	Ability to Quickly Control the Light
β	.231	.196	.155	.108
p	<.001	<.001	.019	.049

Table 8. Effects on Spatial Comfort.

	Spatial Comfort (Error Margin = .85)						
Indicator/Characteristic	Room Height	Room Length	Room Width	Number of Beds	Functionality	View	Interior Design
Weight	.166	.146	.126	.126	.106	.106	.106

Table 9. Predictors of Spatial Comfort.

	Spatial Comfort ($r^2 = .54$)				
Indicator	Enough Space to Host Company (Functionality)	Enough Space to Get In and Out of Bed (Functionality)	Views on Nature (View)	Enough Space for Using Mobility Devices (Functionality)	Appealing Material Used (Interior Design)
β	.246	.202	.156	.161	.138
p	.001	.001	.003	.019	.035

space is especially relevant in terms of safety and security; in the context of well-being, controllability of lighting seems more important.

Indicators that were assigned to the safety and security model, but did not significantly contribute in the regression analysis, are related to additional support from personnel such as that patients could see the availability of personnel. This indicates that as long as personnel can be called from the bedside, patients do not need to see their availability.

Spatial Comfort

Table 8 shows the results of the BP analysis for the spatial comfort model. For this theme, DCs were connected at the same level as some of the SIs (functionality, view, and interior design). At the next level of the BP model, also the effects of SIs or DCs on the SIs, functionality and view were analyzed.

Table 9 shows the results of the hierarchical multivariate regression analysis. The regression model only included the evaluations on the functionality, view, and interior design. Since DCs were connected next to indicators directly below the theme score, the regression and BP analysis could only be partly compared. It appears that functionally, view and materials are significant contributors to the evaluation of spatial comfort, but the dimensions of the room, especially the height, have a stronger effect. Number of beds in the room is also important. Perhaps more beds indicate more space and as a result positively affect spatial comfort. Interestingly, the surface area as such has less effect. The evaluation of the color and general interior design indicators did not significantly contribute to the spatial comfort score.

At a lower level, functionality seems especially determined by the dimensions of the room and number of beds in the room. The number of folding chairs has a relatively large effect on the

Table 10. Effects on Autonomy.

Autonomy (Error Margin = .90)				
Indicator	Food and Drinks Control	Privacy Control	Climate Control	Lighting Control
Weight	.359	.169	.169	.169

Table 11. Predictors of Autonomy.

Autonomy (r^2 = .51)						
Indicator	Food and Drinks Control	Ability to Find Seclusion (Privacy Control)	Ability to Determine Resting Periods (Privacy Control)	Ability to Open the Window (Climate Control)	Ability to Control Room Temperature (Climate Control)	Ability to Control Lighting During the Day (Lighting Control)
β	.266	.147	.133	.127	.112	.105
p	<.001	.006	.021	.009	.027	.047

evaluation of the space in the context of hosting company.

It appears that there is a great variability between how people evaluate the same view (error margins > 1). Interestingly, in general, different aspects of a view are appreciated when standing in the room or lying in bed. While standing, views on people, green environment, and outside traffic have the largest effect. In bed, views on a green environment and the sky have the largest effect. This implies that an outside view on motion (people and traffic) is especially valued when patients have the ability to stand and move themselves. Views on buildings have limited effect from both perspectives. The results also show that the height of the parapet and the window surface are more important in determining the appreciation of the view than, for instance, length or width of the window.

Autonomy

The results of the BP analysis for the autonomy model are shown in Table 10. The results of the hierarchical multivariate regression analysis are shown in Table 11.

The regression analysis corresponds with the BP analysis. The ability to control food and drinks and privacy control has the largest effect on autonomy. Looking at the underlying DCs, it appears that having unwanted views from other outside buildings strongly influences privacy control (.442). Interestingly, the ability to control unwanted views from either the inside or the outside are not significant predictors in the regression analysis, but the ability to find seclusion and determine resting periods are. It could be argued that having unwanted views from outside especially affects the ability to find seclusion or determine resting periods. Since this DC (having unwanted views from outside) was not connected to the indicators ability to find seclusion and determine resting periods, these effects were missed by the BP analysis.

Ability to control the lighting (.355) from the bed (.355) during the day has the strongest impact on the lighting control indicator. Concerning the climate control indicator, the ability to influence the temperature (.279) has the largest effect compared with, for instance, opening a window (.179). The regression analysis shows opposite results. It could be argued that to influence autonomy, the ability to open a window is important; however, in the context of all indicators influencing patient well-being, control over temperature has a larger effect.

Sensory Comfort

The results of the BP analysis for the sensory comfort model are shown in Table 12. Table 13

Table 12. Effects on Sensory Comfort.

	Sensory Comfort (1.02)					
Indicator	Lighting/Day Light	Scent	Fresh Air	Acoustics	Temperature	Hygiene
Weight	.171	.166	.165	.144	.144	.144

Table 13. Predictors of Sensory Comfort.

	Sensory Comfort ($r^2 = .53$)		
Indicator	Temperature During the Day	Temperature During the Night	Enough Daylight
β	.481	.200	.107
p	<.001	.001	.012

shows the results of the multivariate hierarchical regression analysis.

The error margin indicate that the sensory comfort score could not be predicted well (>1). People in the same room differ greatly on their sensory comfort evaluation.

Both analyses show that the amount of daylight is an important characteristic in influencing sensory comfort. The appreciation of the amount of daylight could be predicted with an error margin of 0.73 based on the underlying DCs. The underlying DCs with the largest effect are window surface (.485) and window/room surface ratio (.396).

Interestingly, temperature is considered more important than scent and fresh air in the regression analysis; however, in the BP analysis, temperature is less important. The difference between the BP and regression may be explained by the fact that the BP model optimizes for patient well-being. It seems that scent and fresh air are stronger related to well-being than to the general sensory comfort score, as they do not explain a significant variance in the sensory comfort score. According to the regression results, the evaluation of sensory comfort mainly (53%) depends on the evaluation of the temperature and amount of daylight. Air, scent, acoustics, and hygiene are no significant predictors of sensory comfort.

Social Comfort

The results of the BP analysis for the social comfort model are shown in Table 14. Since there was no general score on room level, the error margin could not be calculated. Also, many social comfort indicators were related to department facilities rather than room facilities. And, the data that were available on room level varied little between the different rooms (e.g., all had Wi-Fi and a telephone). The highest weights (>0.1) of the DCs that did vary on room level and affected social comfort on room level are shown in Table 14.

Table 15 shows the result of the hierarchical multivariate regression analysis. The indicators of social comfort only explained 26% of the variance in social comfort, the lowest explained variance of all general theme scores. Both analyses show that a view on activities in the department is a strong predictor of social comfort on room level. Folding chairs and enough space (# beds/ surface area room ratio) to use them to host company have a large effect. The number of beds and a sky view also affect social comfort. Characteristics with less impact are inside view on a traffic area; outside view on green, buildings, people and traffic; and the distance to the reception desk or public room.

Privacy

The results of the BP analysis for the privacy model are shown in Table 16. Only indicators or DCs with weights exceeding .1 are reported. Table 17 shows the results of the hierarchical multivariate regression analysis.

The privacy score has the highest error margin of all theme scores (1.15) and indicates that the privacy score could not be fitted well on the underlying indicators and DCs. This indicates that people have very different perceptions of

Table 14. Effects on Social Comfort.

	Social Comfort					
Indicator/Characteristic	Open Door	# Folding Chairs	# Beds/Surface Area Room Ratio	Number of Beds	Inside View on Public Area	View on Sky
Weight	.312	.281	.277	.142	.118	.110

Table 15. Predictors of Social Comfort.

	Social Comfort ($r^2 = .26$)		
Indicator	Views on Activities (in Department)	Ability to Host Company	Distraction Offered in the Room
β	.297	.215	.152
p	<.001	<.001	<.001

Table 16. Effects on Privacy.

	Privacy (Error Margin = 1.15)		
Indicator/ Characteristic	Room Height	Room Length	Storing Space
Weight	.126	.111	.111

Table 17. Predictors of Privacy.

	Privacy ($r^2 = .39$)		
Indicator	Ability to Have a Private Conversation	Unwanted Views From the Corridor	Personal Storage Space
β	.442	.217	.104
p	<.001	<.001	.029

privacy even though they are in the same environment. Looking at the general contributors, it appears that room length and height have a relative strong effect on privacy. Personal storing space comes next according to the BP analysis; however, ability to have a private conversation turns out to be the greatest predictor in the regression analysis. Interestingly, number of beds, surface area, unwanted views, and ability to have a private conversation (on room level) had less impact in the BP analysis (<.1). The difference between the BP and regression analysis may indicate that the ability to have a private conversation strongly contributes to feelings of privacy however is less related to the overall well-being score.

Discussion

Relative Impact of Themes and DCs on Patient Well-Being

The aim of this research was to identify the impact of DCs of a patient room on self-reported patient well-being. We found that if hospital administrations want to upgrade their patient rooms into healing environments (in this case meaning an environment that increases self-reported patient well-being), they should focus on spatial comfort, safety and security, autonomy, and associated DCs for the strongest impact. In terms of DCs, this means for spatial comfort do not compromise on the dimensions of the room. The larger and especially the higher the room is, the better. Also, the cleaner the room looks, the better. Functionality, views on sky and green, appealing materials, personal storage space, and space for private conversations are also important. Considering safety and security patients appreciate the feeling that unauthorized persons have restricted access to the patient's room. Concerning facilities in the room, it includes lighting that can be adjusted by the bed, safe personal storage space, and the ability to call personnel from the bed. Especially the availability of food and drinks is important to influence feelings of autonomy, but the possibility to find seclusion, determine resting periods, control lighting, and indoor climate settings also has impact.

We found that if hospital administrations want to upgrade their patient rooms into healing environments *they should focus on spatial comfort, safety and security, autonomy, and associated DCs for the strongest impact*

The impact of social comfort on well-being should not be misinterpreted based on the BP analysis on room level. Social comfort had no score on room level (as the question was stated on department level) and as a result was calculated based on underlying indicators in the BP analysis. To conduct the regression analysis, the social comfort score on department level was selected. Social comfort on department level is a significant predictor of patient well-being. Furthermore, communication was a significant design factor predicting patient well-being in the regression analysis. This indicates that the possibility to communicate to other patients, family, and friends in the room or at the department is important for impacting social comfort and well-being. Since a social comfort room score was lacking and the communication items were not included on room level in the BP model, it explains why social comfort had only limited impact on well-being in the BP model.

Sensory comfort was not a significant predictor of well-being and only had a limited impact on the BP analysis. This could be explained by the fact that the influence of sensory comfort is often unconscious and may only affect people if it is outside the comfortable range (de Korte et al., 2015). It seems that the rooms in our data set were not uncomfortable enough to have a systematic impact on well-being evaluations. Furthermore, sensory comfort could not be well predicted. The fact that all indicators are ambient factors that could differ on a day-to-day basis in the same room might explain this result. Still, the results of this research do provide a relative hierarchy of indicators influencing sensory comfort.

Interestingly, privacy contributed the least to patient well-being in the BP analysis and was not a significant predictor of well-being in the regression analysis. This finding is also supported by the fact that no privacy indicators were included in significant design factors impacting well-being. It implies that the way patients evaluate privacy in a hospital setting in general is not strongly related to the evaluations of patient well-being. Since it is a hospital and not a hotel, people may accept lower levels of privacy, which makes the theme less relevant. It should be noted that 75% of the sample was older than 46 years. The 65+ age-group rated the privacy theme score more positively than younger age-groups, which indicates that this group have other privacy norms than the current young and future population. The results may therefore not be applicable to younger age-groups.

BP Model Considerations

This research shows that it is important to validate assumed connections in the BP model, as effects of lower order indicators may be diminished when higher order indicators are not significantly related to KI at the top of the model or when lower order indicators are incorrectly assigned.

This for instance may explain why spatial comfort was more important in the regression analysis than in the BP analysis. Based on the factor analysis, it appeared that the privacy indicators, ability to have a private conversation and personal storage space, loaded highest on the design factor spacing which is more related to spatial comfort than privacy. This indicates that spatial comfort also depends on social and privacy features of a room. This is in line with literature (Buttimer & Seamon, 1980; Sixsmith, 1986) that states that comfort evaluations are based on the functional, personal, and social evaluation of a room. It could be argued that due to the fact that in the BP model these privacy indicators were not connected to spatial comfort, but to privacy, the effect of spatial comfort was less strong in the BP analysis. Furthermore, since privacy was not a significant predictor of well-being, the effects of these privacy indicators (that actually belonged to spatial comfort) were diminished.

This also applied to the hygiene indicators connected to sensory comfort and included in the design factor hygiene. This design factor was a significant predictor of well-being. Since the hygiene item did not predict sensory comfort, and sensory comfort was not a significant predictor of well-being in the regression analysis, the effect of the hygiene item was diminished in the BP model. In an additional analysis, it appeared that items in the hygiene factor were significantly related to spatial comfort, indicating that hygiene evaluations influence spatial comfort and not sensory comfort. It also explains why sensory comfort was more important in the BP analysis compared with the regression analysis (as the hygiene item was connected to sensory comfort).

The fact that safety and security was the most important theme based on the BP analysis but not based on the regression analysis could not be explained by the incorrect assignment of indicators. Interestingly, safety and security and autonomy ranked in the top three (both analysis techniques) of most important themes but did not have any indicators in design factors that contributed significantly to well-being. A reason could be that variance in patient well-being was no longer explained due to the grouping of the indicators by the factors. For example, the availability of food and drinks is an important single predictor of the autonomy theme and as an effect contributed to the effect of autonomy on well-being. In the factor analysis, this item was grouped with lighting control items, which as a group had no significant effect on well-being. In the BP analysis, all indicators are taken into account individually including the DCs (unlike the regression model), which could also explain the difference. Further research is needed to better understand the difference in hierarchy.

Strengths and limitations

A strength of this research is that we introduced a machine-learning technique to connect physical environmental input to subjective measurements of that environment. We created a BP model that is able to predict patient well-being based on DCs. When this BP model is restructured based on the results of this research and validated in a more varied context, it can be used to support design decisions before the realization of a hospital building. In this way, designs can be optimized for patient well-being already on the drawing table, instead of after refurbishment. In addition, the model can be used in postoccupancy evaluations, by quickly showing the overall performance of a building and areas for improvement, which could be validated in a focused and efficient way with user groups.

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In this way, designs can be optimized for patient well-being already on the drawing table, instead of after refurbishment.

Some remarks on the use of the BP model should be made. First, the BP model predicts for the average patient (which does not exist). This applies when designing for a general health facility. However, when designing for a special patient group, application of the general model may be less suitable. When we looked at the data of different patient groups, we found that level of education, age, and perceived severity of the illness significantly impacted the evaluations. In general, lower educated patients, older patients, and patients who perceive their illness less severe score their environment more positively. This has implications for the design of buildings for special patient groups and, moreover, patient evaluations should always be controlled for at least these patient characteristics. Since type of illness was not recorded, effects could not be tested. Further research is needed to find out if there are specific environmental needs for patients with a certain diagnosis.

Second, currently all design information need to be inserted manually to operate the BP model, which is very time consuming. The aim should be to connect this BP model, when validated, to a building information model (BIM) in such a way that the BP model is automatically filled with the building data available in BIM. In this way, performance information will be continuously updated when new building information is added in BIM.

A limitation of the research is that we first gathered 350 patient evaluations in one hospital environment to first train the model. In order to derive at a more general model, data of three different locations were added. Although the model could be better trained with the four locations and effects could be controlled for location impacts, a bias to the hierarchy found in this one location still exists. Therefore, updating the model with more different locations and varied physical data is needed. Thus, although the model needs further testing, we showed a methodology to visualize and predict the impact of many DCs on patient well-being and identified themes to improve for a healing environment upgrade.

Finally, we measured self-reported well-being that differs from the more objective physical well-being or health of a patient. Therefore, the results should be interpreted as the characteristics that contribute most to well-being in the opinion of patients irrespective of whether there is a real health effect.

Implications for Practice

- Spatial comfort, safety and security, and autonomy and associated DCs seem the most influential themes to increase self-reported patient well-being.
- The developed model enables to predict self-reported patient well-being based on design input.
- When validated, the model can be applied to optimize design decisions in an early design stage (before the realization of the building) but can also be used to conduct postoccupancy evaluations.

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