Title

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Author

Kent, Michael George

Publication Date

2018-12-05

The importance of window view: Using an exploratory factor analysis to uncover the underlying latent dimensions

Michael G. Kent[a,b*]

[a] Department of Architecture and Built Environment, University of Nottingham, United Kingdom
[b] Berkeley Education Alliance for Research in Singapore (BEARS) Limited, Singapore

Corresponding author: michaelkent@berkeley.edu

Abstract

This report outlines a statistical method used to evaluate the subjective ratings given to an image of a window view. An online survey containing questionnaire items that I believe influence the observer's perception of the view were listed and distributed online. In total, 181 subjective responses were collected. Participants were asked to rate each item in the survey based on the perceived level of agreement or importance for each question. To analyse the data, I used an exploratory factor analysis. Of the 30 question items listed in the survey, four underlying latent factors were extracted. Namely: 'subjective responses to the window view', 'physical features of the view', 'physical features of the window', and 'work-related responses', respectively. These are listed in order of the amount of variance that they could explain within the data. The results of the analysis show how responses to several different questionnaire items refer to the same latent factor. I believe that the findings can be used towards the development of a predictive model to evaluate window view satisfaction. Specifically, when measuring a smaller, but manageable number of subjective responses in a survey to explain a complex construct of human behaviour such as the perceived importance of window view.

1. Introduction

From the perspective of human vision, it is often believed that windows serve two main purposes. The first is to bring daylight into an indoor occupied space and the second to provide a view to the outside (Kaplan, 1993). In fact, it is daylight itself that contains visual information from the outside that is transmitted into the building through the window glass (Tregenza and Wilson, 2013). Since humans spend a significant amount of time inside buildings (Gifford, 1995), the visual information that provides connection to the outdoor environment plays an important role when maintaining the psychological and physical health of the occupants (Veitch and Farley, 2001).

The clearest distinction between different views can be made when they are classified as either urban or natural (Tennessen and Cimprich, 1995). Studies have shown that natural elements (e.g., trees, fields, water, etc.) in the view can relieve symptoms of fatigue and improve subjective levels of comfort in individuals (Fjeld, 2000; Kaplan, 1995). These findings can apply when natural elements are found both inside or outside of the building (i.e., as indoor décor or when they are seen in the window view) (Chang and Chen, 2005). Research in hospitals has also shown that a view of nature can lead to shorter patient recovery times following surgical procedures (Ulrich, 1984). Different views can even change the perception of time, creating a sensation that it is passing slowing when an individual is presented with images of a natural setting (Berry et al., 2015; Davydenko and Peetz, 2017). Conversely, views of predominantly urban scenes (i.e., in the absence of natural elements) do not appear to display the same positive influences (Bratman et al., 2015; Ulrich, 1991, 1986).

According to Collins (Collins, 1976): "*there is difficulty in determining the best size, shape and position of a window to meet occupant needs*". Kaplan (Kaplan, 2007) studied multiple building typologies showing that employees often reported a higher preference to visual scenes that contained nearby foliage and less visible sky. Findings related to three different urban spaces featuring various built and natural elements has shown that short-term visits to natural environments could be associated with lower levels of the stress hormone cortisol (Tyrväinen et al., 2014). Window views of nature from residential dormitories appear to be linked to greater capacity to direct attention, with positive effects on performance and self-assessments (Tennessen and Cimprich, 1995). In office-based environments, Kwoen *et al.* (Kweon et al., 2008) discovered that male occupants displayed lower levels of anger and stress when paintings of nature were present. However, despite the scientific evidence suggesting that views containing natural elements are linked to favourable effects, there is still uncertainty on the key elements that underlie these positive responses (Velarde et al., 2007). To date, it remains unclear what important design considerations are needed to give provision for the window view in order to provide access to beneficial influences they can bring to building occupants.

In this report, I present a pilot study used to investigate the latent factors that are considered to be important when evaluating an image of a window view. A latent factor is commonly defined as a hidden or unobservable variable that is part of a larger construct, which also plays a role in human behaviour (Borsboom et al., 2003). However, constructs are usually comprised of many underlying latent variables and it is often of interest to some researchers to investigate their statistical structures (i.e., the covariance among the observed variables) (Wildt et al., 1978). One method of analysing these statistical structures is to perform a factor analysis (Conway and Huffcutt, 2003).

Here I will outline a statistical method used to explore the complex relationships that exist between the window, its view and the observer, in order to understand what variables need to be considered when providing a view for the building occupants. I believe that there are several factors underlying the observer's perception of the window, which may be used to determine what they may or may not desire from any given view. These findings could then be integrated towards the development of a model that measures the subjective responses given from different window views.

2. Method

2.1. Experimental design

2.1.1. Participants

A total of 181 participants volunteered to complete an online survey. All were students and staff from the University of Nottingham (United Kingdom), 104 male (57.5%) and 77 female (42.5%), the age of the sample ranged from: 18-20 years = 13 (7.2%), 21-29 years = 62 (34.3%), 30-39 years = 43 (23.8%), 40-49 years = 28 (15.5%), 50-59 years = 29 (16%), and 60 years or older = six (3.3%). Ethnicity varied from: white = 140 (77.3%), black or African-American = one (0.6%), Asian = 24 (13.3%), multiple races = three (1.7%), prefer not to say = four (2.2%), and other = nine (5%).

2.1.2. Data collection

An online multiple item-response survey featuring 30 questions measured on a five-point likert rating scale was used for this study (Field and Hole, 2011). In the questionnaire, I asked participants to evaluate an image of a window view (Figure 1) as seen from inside an office room when the observer is sat at the viewing position. I had captured the image at the beginning of March under a fully overcast sky at the Department of Architecture and Built Environment, University of Nottingham, United Kingdom (latitude: 52°56’19” N; longitude: 1°11’42”W). For the purpose of this study, a photographic image (Figure 1) was preferred as the visual stimulus to be presented to observers in order to overcome several important constraints that could have not been experimentally controlled (i.e., natural light levels, weather patterns, daily and seasonal changes, etc.).

Figure 1. Photographic image of the window view as seen from inside the test room.

Since the most important factors that can be used to describe a window view are not yet known, I listed candidate variables identified from the literature. From this list, a series of variables were selected as featured items on the survey questionnaire (see Appendix). For example, the architectural features of a window (i.e., its shape and size) are generally considered to play a significant role on its view (Collins, 1976). Thus, it is no surprise that larger windows are preferred since they offer more view to the outside (Ne’Eman and Hopkinson, 1970). The glazing type that acts as the barrier between the indoor and outdoor environments also impacts on the window view, influencing the perceived quality of the daylight transmitted to the building (e.g., its brightness, pleasantness) (Dubois, 2009).

The content of the visual stimulus is another important characteristic of the view (Tuaycharoen and Tregenza, 2007). Markus (Markus, 1967) originally suggested that the layered structure of the elements strongly influences the general quality of the view (e.g., stratification). For example, views containing several layers (i.e., ground, buildings and a skyline) are more desirable than those containing only a single layer. As previously described, both natural and urban elements found in the view can influence various psychological and physiological responses (Kaplan and Talbot, 1988).

Among many candidate variables that could have been listed, the connection that a window view brings to the outdoor environment may be one of the most pertinent (Biner et al., 1993). From a review of the literature, however, many variables appear to be relevant to consider when providing window views. These not only include physical parameters, such as the dimensions of the window, but also non-visual variables including psychological factors strongly aligned to our emotions and factors used to describe the physical structure and visual content of features seen in the window view.

2.1.3. Procedure

The survey featured two sets of descriptors requiring participants to evaluate a statement based on their level of agreement with it or the importance given. In one series, the scale descriptors ranged from: strongly disagree (1) to strongly agree (5). These extreme points were equally balanced about a neutral criterion ((3), neither, agree or disagree) at the centre of the evaluation scale. This set of descriptors was applied to 12 out of 30 items that appeared in the survey. In the other series, the scale descriptors ranged from: 1 = not important (1) to very important (5) with a neutral mid-point, ((3), neither, important or not important). This set of descriptors was applied to the remaining 18 items.

At the top of the online survey, an image of the window view was presented along with a set of instructions and the following statement: "*Imagine this is your own personal workstation – equipped with a computer, screen, keyboard and mouse on a computer desk – and that you are sitting here working on your daily activities. In front of your desk is a window providing a view of the outdoor environment, which is illustrated in the image on the right* [Figure 1]. *The image portrays the view that can be seen from the position you are seated when working at your workstation*".

3. Statistical analyses

A total of 181 responses were collected from the online surveys.

I first used a Cronbach's alpha (α) to estimate the internal consistency of the measurement scale (Cronbach, 1951). This method describes the extent to which all survey responses correspond to the same construct by determining the internal relationship of the items specified in the survey, whereby larger values signal a higher degree of reliability (Tavakol and Dennick, 2011). When determining the reliability of the scale by considering all survey questions, values of α ranging between 0.70-0.80 are regarded as 'satisfactory' (Bland and Altman, 1997). The Cronbach's α here was 0.70 for my survey responses collected. The reliability matrix shows that the removal of 25 out the 30 questionnaire responses would decrease the α value. Of the other five items in the survey, removal of these would only increase the α by 0.01. I concluded that all variables listed in the survey items are reliable.

To analyse the data, I used an exploratory factor analysis (EFA) to identify latent variables that can be used to describe the relationships that exists between groups of correlated variables (Field, 2013). In most cases, when performing an EFA, the researcher has some idea of how certain variables are related before collecting any data (Costello and Osborne, 2005). This increases the amount of common variance that exists among correlated variables and creates regression weights that allow the researcher to find the most important latent variables in the data (Floyd and Widaman, 1995). In other words, the analysis serves as a method of explaining a common domain of interest by identifying a small number of underlying factors from a larger subset of items (Fabrigar et al., 1999).

To aid in the interpretation of the outcome, I selected the varimax (i.e., orthogonal) structure rotation method to help interpret the data (Osborne, 2015). This method extracts only the factors containing a high number variable loadings, but does not allow these factors to correlate with each other (Kaiser, 1958). Therefore, only the factors that contain a high number of correlated survey items are retained from the analysis, and those with a fewer number of correlations or common variance can be discarded as they are assumed to be caused due to measurement bias or noise (Abdi, 2003)

To determine whether there is sufficient amount of common variance among the variables, and therefore indicates the presence of hidden latent factors, I used the Kaiser-Meyer-Olkin (KMO) test of sampling adequacy (Kaiser, 1970). This creates an index with values that range from 0 to 1, whereby a value closer to 1 indicates more distinct correlation patterns in the data (hence, demonstrating that a factor analysis is more appropriate). This test revealed a KMO index corresponding to 'middling'= 0.79, hence suggesting that the sampling was somewhat adequate.

When performing an EFA, an important assumption is that the explanatory variables (i.e., survey items) have a linear relationship with each other (or, in order words, multicollinearity). To test this assumption, the Bartlett's test of sphericity showed that the correlation matrix of variables is statistically different from the identity matrix with no collinearity: $\chi^2(435)= 1\ 684$, $p \leq 0.001$. This demonstrated that this assumption has also been satisfied before performing the EFA.

4. Results and discussion

Figure 2 presents the results of the EFA using a scree plot analysis. Along the x-axis, the figure presents the number of factors identified. On the y-axis, the eigenvalues are given, these providing an indication of the amount of variance that can be accounted for by each factor. Higher values show that the factor explains more variance (Field, 2013). According to the Kaiser's criterion, all factors that contain an eigenvalue greater than one should be retained, this corresponding to 10 factors in the scree plot (Cliff, 1988). However, it has been considered that this value does not always return the best interpretation of results for certain data sets (Costello and Osborne, 2005). In fact, when examining the scree plot, it appears that the 'point of inflection' (i.e., where the eigenvalues start to level off) occurs at factor 3 or 4. I decided to extract a total of four factors from the EFA for further analysis.

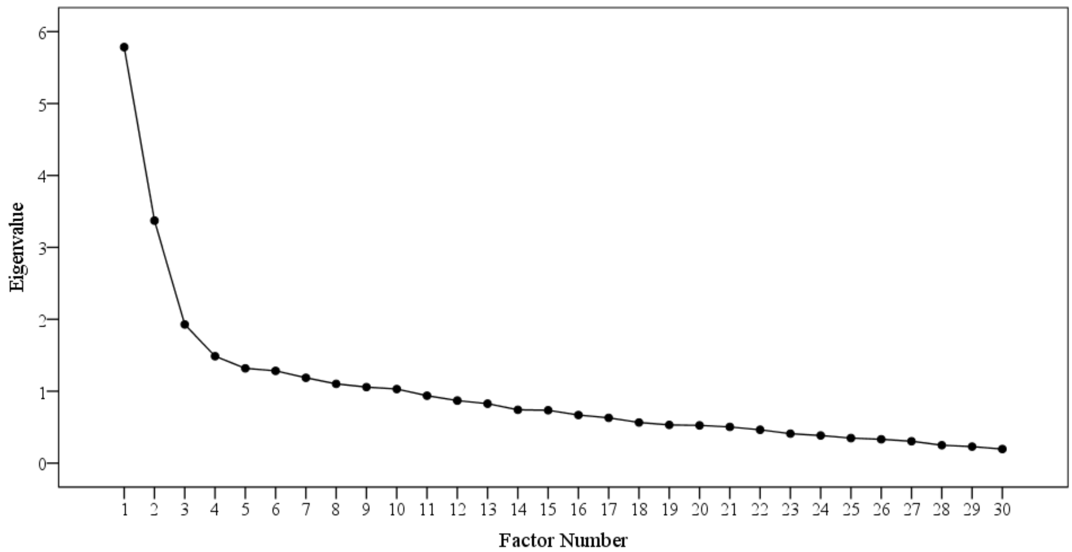

Figure 2. Scree plot displaying the number of factors identified from the EFA.

Table 1 presents the four factors extracted from the EFA, their corresponding eigenvalues, the amount of variance explained, and the cumulative amount of variance explained in the data.

Table 1. Statistical values from the four extracted factors taken from the EFA

Factor	Eigenvalue	Variance Explained (%)	Cumulative Variance (%)
1	5.78	19.28	19.28
2	3.37	11.24	30.52
3	1.93	6.43	36.95
4	1.49	4.96	41.91

Since factor 1 contains the highest eigenvalue out of all other extracted factors, it also explains more variance from the observed variables. To provide a more rigorous analysis of this data, I compared each of the factor loadings to identify how the variables related to each other.

Table 2 presents the loadings for each variable for each of the four extracted factors from the EFA. To aid in the interpretation of each factor, correlation coefficients below 0.30 were supressed to prevent cross-loading (i.e., variables loading onto more than one factor) when possible. For each factor, the correlation coefficients have been organised according to the strength of the association between the variables. Therefore, stronger correlations appear before weaker ones in each of the respective factors. It is also important to note that, despite several attempts to avoid cross-loading, some survey items appear in more than one factor. This demonstrates there are strong relationships that exist between several factors that cannot be easily suppressed, but also have an important role on the importance of the window view.

Table 2. Factor loadings from the EFA

Survey item	Factor			
	1	*2*	*3*	*4*
The view looks pleasant (i.e., could make me feel happy)	0.83			
The view could help reduce stress	0.77			
The view could make me feel relaxed	0.76			
The view looks engaging	0.71			
The view looks peaceful	0.69			
I feel like I could work well in front of this window view	0.58			0.41
The view looks open (i.e., spacious)	0.58			
I would frequently look at this view if this was my workstation (i.e., when taking a break from work)	0.56			
The view provides a connection to the outside (time of day, seasons, weather, etc.)	0.44			
The outdoor environment looks safe	0.42			0.32
There is nothing inside the room obstructing the window view				
The view of the trees		0.60		
The view of the sky		0.55		
The proximity of outdoor elements (i.e., the position of the trees)		0.54		
The colour of the various elements seen within the view		0.51		
The view of the ground (i.e., grass, hills)	0.34	0.46		
The diversity (i.e., the mixture of elements (trees, buildings) seen within the view)		0.40		
The view of wildlife (i.e., birds, squirrels)				
The location of the view (i.e., the level of privacy)				
The window frame			0.66	
The depth of the window sill			0.50	
The shape of the window (portrait or landscape)			0.48	
The size of the window		0.34	0.43	
The type of glass used for the window			0.42	
The window can be opened or closed			0.39	
The view of distant buildings			0.37	
There are blinds available to be used				
The view is very active (i.e., presence of movement outside)				
I feel like I can concentrate	0.40			0.82
The view might distract me from working				-0.49

The next stage of the analysis is to explain the commonality that exists between the variable loadings seen in each factor based on the how each survey item appears in Table 2. The EFA shows that there are 12 variables that load onto factor 1, seven variables that load onto factor 2, seven variables that load onto factor 3, and four variables that load onto factor 4. Since factor 1 contains the highest eigenvalue, naturally it also has more variables correlated and that loaded onto it.

It is the responsibility of the researcher to interpret the factors extracted from the analysis. In summary, the four factors extracted from the EFA are: factor 1: 'subjective responses to the window view'; factor 2: 'physical features of the view'; factor 3: 'physical features of the window'; and, factor 4: 'work-related responses'. The interpretation I have given to each factor is described below.

A review of the survey items in factor 1 shows that most variables describe subjective responses related to the window view (i.e., pleasant, relaxed, peaceful, etc.). Since participants were asked to respond based on their level of agreement or importance given to the statement, all correlation coefficients appear positive in factor 1. In other words, if participants provided a higher rating for a survey item (e.g., the window looks pleasant), they were more likely to also give higher ratings for all other variables belonging to the same factor (e.g., they would agree that the view could help reduce stress). Therefore, higher correlation coefficients signal a stronger relationship with other variables that load into the same factor.

The survey items belonging to factor 2 correspond to specific physical features that are contained within the window view (e.g., trees, sky, ground, etc.). However, it can be postulated that survey items such as 'the view of the ground (i.e., grass, hills)' could load onto both factor 1 and 2. This suggests that some of the physical features of the view correlate with the subjective responses seen in the first factor. Therefore, participants that provided a higher rating of importance for the ground features gave also a higher level of agreement when rating the survey items seen in factor 1.

In factor 3, most survey items identify physical features of the window (e.g., the window's frame, sill, shape and size, etc.). Similar to factor 2, most survey items were rated by participants based on their level of importance. Therefore, most physical aspects of the window view have a direct relationship with each other. In fact, participants that gave a higher rating for the window shape were also likely to provide a higher rating for the window size. As a result, the size of the window also appears to cross-load onto factor 2, signalling a positive relationship between the physical features of the window and those seen in the view.

The remaining variables load onto factor 4. For this factor, only four survey items were found to correlate with each other, describing the relationships between several work-related responses. Participants that strongly agreed they could work in front of this window view (i.e., 'when imagining this would be their own workstation'), also gave lower ratings when responding to the statement: 'the view might distract me when working'. This signals an inverse relationship between variables.

5. Conclusions

This pilot study outlines a method to identify the factors that are important to test participants when observing the image of a window view. The results revealed four latent factors. Factor 1 (i.e., 'subjective responses to the window view') explained most of the variance within the data, while other physical factors of the view and the window could be extracted from the analysis. A final factor, labelled 'work-related responses', demonstrated that certain aspects of the window view may also be important for focussing and concentrating on task related work.

This method of data collection and analysis could be used towards the development of a prediction tool for evaluating window views within buildings. Since no window will contain the same visual content, it would be important to measure only the most important aspects that contribute to the occupant's overall impression of the view. For example, rather than collecting responses related to the physical features of the view separately (i.e., as previously demonstrated in another study of window view (Hellinga and Hordijk, 2014), this can be done by providing an overall rating of the visual content seen. That is, the physical features (i.e., trees, sky, buildings, etc.) belong to the same latent factor that can be used to describe the construct of window view importance. Therefore, when a rating for one specific aspect changes, the responses given for the others will also vary accordingly.

The factors provide a method of identifying the key dimensions that influence the subjective responses given (i.e., importance of the window view). For example, the physical features of the view and other window elements influence ratings given to items describing positive qualities that would promote the observer's psychological state and their ability to work in the indoor environment. Although it must be acknowledged that the factors extracted are dependent on the subjective dimension that is measure (i.e., the degree of satisfaction, importance or interest in the view).

Before this method can be fully developed, however, it is important to consider several limitations to this study that would need to be addressed in future work. Firstly, the photographic image contained many desirable characteristics (i.e., nature, skyline, etc.). This might have influenced the positive ratings given for certain elements seen in the visual stimulus. It is not clear whether the same four factors would have been uncovered if an image with no desirable traits was evaluated (e.g., an image showing a view covered entirely by a brick wall). Secondly, the factors extracted from the EFA are dependent on the survey items derived from the literature. Since many of them described subjective responses to views, this could explain why most items loaded onto the first factor, and why this was also able to explain most of the variance within the data. Therefore, I think the survey needs to be refined to ensure only the most relevant dimensions of the window view are considered. These statements would ideally be validated through secondary methods (i.e., observation techniques, focus groups, etc.) before being distributed. It has been shown that there are differences in the subjective responses given when an individual is presented with an image and when they are in direct contact with nature (Brooks et al., 2017). Therefore, I believe at some stage evaluations here will need to be verified under daylit conditions (i.e., from real windows with access to an outdoor view).

Acknowledgements

The data from this study was collected and analysed while I was affiliated to the University of Nottingham (United Kingdom), the report was written and revised while at the BEARS. I want to thank Professor Sergio Altomonte (Université Catholique de Louvain) and Dr Stefano Schiavon (University of California, Berkeley) for their feedback about this work.

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Appendix: Online survey

When looking at the image, please rate the following.

	Strongly disagree	Disagree	Neutral (neither agree nor disagree)	Agree	Strongly agree
The view might distract me from working	○	○	○	○	○
The outdoor environment looks safe	○	○	○	○	○
The view looks peaceful	○	○	○	○	○
This view could make me feel relaxed	○	○	○	○	○
I feel like I can concentrate on my work in front of this window view	○	○	○	○	○
This view could help reduce stress	○	○	○	○	○
I would frequently look at this view if this was my workstation (i.e., when taking a break from work)	○	○	○	○	○
The view provides a connection to the outside (i.e., time of day, seasons, weather, etc.)	○	○	○	○	○
The view looks open (i.e., spacious)	○	○	○	○	○
The view looks engaging	○	○	○	○	○
The view looks pleasant (i.e., could make me feel happy)	○	○	○	○	○
I feel like I could work well in front of this window view	○	○	○	○	○

When looking at the image, please rate the importance of the following.

	Not important	Not very important	Neutral (neither, not important nor important)	Important	Very important
The diversity (i.e., the mixture of elements (trees, buildings) seen within the view)	○	○	○	○	○
The proximity of outdoor elements (i.e., the position of the trees)	○	○	○	○	○
The view of wildlife (i.e., birds, squirrels)	○	○	○	○	○
The location of the view (i.e., the level of privacy)	○	○	○	○	○
The view of the trees	○	○	○	○	○
The type of glass used for the window	○	○	○	○	○
The size of the window	○	○	○	○	○
The colour of the various elements seen within the view	○	○	○	○	○
There is nothing inside the room obstructing the window view	○	○	○	○	○
The depth of the window sill	○	○	○	○	○
The view of the sky	○	○	○	○	○
The view is very active (i.e., presence of movement outside)	○	○	○	○	○
The view of other distant buildings	○	○	○	○	○
The window can be opened or closed	○	○	○	○	○
The window frame and bar	○	○	○	○	○