

BIG DATA AS INNOVATIVE APPROACH FOR USABILITY EVALUATIONS OF BUILDINGS

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ABSTRACT

Purpose: The purpose of this paper is to investigate how Big Data can add a new dimension to usability evaluations of buildings.

Background: There is a tremendous growth in the volume of available data, creating the “Big Data” trend. Industries such as IT, retail and transportation can present a number of examples of successful applications of Big Data. Usability has traditionally been analysed by qualitative research methods, and Big Data gives an opportunity to add quantitative data in such evaluations.

Approach: The study is based on literature research and interviews with 15 professionals in IT facilities management and government agencies. We discuss potential data that can be used for usability evaluations of buildings.

Results: Big Data is creating new opportunities to analyse a phenomenon based on different types of data. Interesting data categories include: internet traffic, movement-related data, physical environment data, typically from different types of sensors and commercial activity. Possible problematic issues related to use of Big Data are availability, applicability, relevance, privacy policy, ownership, cost and competence. The study indicates that none of the challenges need to hinder use of Big Data when evaluating the usability of in buildings evaluation, provided that the issues are properly managed. We present a sample of Big Data that may be used for evaluation of building usability.

Practical Implications: Our conclusion is that there are major advantages in using Big data, increasing the opportunities for the evaluator to find indicators that are relevant to the building being evaluated. Use of Big Data can serve as a step towards a stronger technology focus in usability evaluations of buildings, and thus support innovation in building design and facilities management.

Research limitations: The research is mainly done in a Norwegian context.

Originality: We have found few previous studies that explicitly link Big Data and evaluation.

Keywords

Big Data, Building performance, Facilities management, Usability, Evaluation.

1 INTRODUCTION

This paper studies how Big Data can be used in evaluation of buildings, seen from a Facilities Management (FM) perspective. FM is an interdisciplinary approach, integrating principles of business administration, architecture, and the behavioural and engineering sciences (Cotts et al. 2010). Usability evaluations are based on different user's experiences and assessments on how well buildings perform and are related to fulfilment of user needs (Harun et al. 2011). Such usability evaluations are typically based on architecture and the behavioural science. Another approach to building evaluation is Post occupancy evaluation (POE). Since the 1980s the methodology has been developed with focus on POE and building performance evaluation (BPE), as shown by Preiser et al. (1988). As pointed out by Alexander (2010), the emphasis of POE is mainly on the building, while usability appraisal seeks to evaluate the user experience.

Access to good relevant data can be a challenge when evaluating large public building investments (Volden and Samset 2012). This may seem like a paradox, when the volume of data generally increases. However, experience show that data related to the building construction and physical performance of the finished building has been relatively easier to obtain, compared to data that illustrate the user experience of the building. This has been the starting point for looking at the potential of using Big Data in the evaluation of buildings. We have found few publications that explicitly reviewing the use of Big Data for evaluation. In spite of this, there are examples of Big Data that could have relevance to the evaluation of buildings. Some of the examples we have found have a potential to address the user experience of a building. We therefore see a potential for Big Data to be considered as information about the building and its users like required by usability researchers: "*A building's usability is never dependent just on the building itself. It should be seen in the light of the relationship between building and user*" (Lindahl et al., 2013, p. 114). Alexander (2010) has studied the successful interaction between the building, its users and the IT infrastructure with the focus on learning environments. He states that: "*Effective learning environments successfully combine appropriate social and digital environments with the physical environment.*" (Alexander, 2010, p.15)

Big Data is a relatively new term that gained acceptance in 2009 (Manyika et al. 2011). A common definition of Big Data is datasets that are so large that they are not suitable to collect, store, process or analyse using traditional database tools (Nature, 2008; Manyika with several 2011). Big Data has some characteristics that make it different compared to structured data in a database. The term "the three Vs" referring to volume, velocity, variety are widely used (Russom 2011). Another characteristic is the availability of real time data. The most important characteristic inherent in the term is that we are talking about data at a large volume. Manyika et al. (2011) state that the global data volumes grow by 40% annually. Data volumes are so large that they are measured in exabytes (one trillion bytes).

There has been a rapid development in the area of Big Data in recent years. The following important developments are worth noting:

- Large quantities of data become available, including data from the internet and data based on sensor and tracking technology
- Increased pressure for making data available
- Access to storage and analysis capabilities at low cost.

- Access to IT platforms to put data into context, such as digital maps for presentation of position data, or building information models (BIM)

Big Data requires new approaches to data analysis for several reasons. Two of the main factors are the size of the data and the unstructured format of the data. Both these factors means that many of the existing data analysis tools struggle to realise the potential of Big Data. Data from multiple sources are aggregated and analysed in new contexts. The potential lies in the linking of data and the ability to see patterns and trends, providing opportunities to extract new knowledge. It is not just access to dynamic data has increased, but also static data digital maps and building information models has become common and readily available. This means that it is now easier to present data in a relevant context.

Hildberg (2013) proposes a classification of different types of data and data sources based on tracking words, locations, nature, behaviour, economic activity, and finally tracking other data. Related to the evaluation of buildings we suggest a division into the following categories according to how data is collected or generated:

- Internet traffic, including activity on social media and data from search engines
- Movement-related data, including GPS, RFID
- Physical environment, typically from different types of sensors
- Commercial activity, the use of payment services and consumption patterns

In addition, there are growing numbers of organisational internal data from FM systems, which is of interest even though the volume does not yet qualify as Big Data.

2 STATE OF THE ART

According to OECD (2000) an evaluation is defined as a “*Systematic and objective assessment of an ongoing or completed project, program or policy, its design, implementation and results*”. Buildings can be evaluated by multiple dimensions, including (Vitruvius, 1960) classic requirements that buildings must fulfil; *firmitas* (strength), *Utilitas* (appropriateness) and *Venustas* (beauty).

Traditionally, most owners and occupants, rarely perform evaluations of how well their buildings perform related to usability aspects. Based on an extensive literature study, Haron et al. (2012) show that usability is a wide concept. As a consequence, several authors (including Jensø et al. (2004), Blakstad et al. (2008) and Blakstad et al. (2010)) argue that evaluations should be based on different methods and aspects, depending on objective, purpose, focus, competence and resources. A systematic evaluation of buildings in use should be an effective way not only to collect information, but also to produce knowledge in relation to the planning of new buildings and for the development of existing buildings.

The term usability has been adapted to buildings through the work in the CIB W111 Usability of workplaces (Alexander, 2004). Usability can be defined as “*the extent to which a system can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use*” (ISO, 1998). Buildings can be regarded as products to achieve

strategic goals such as productivity, innovation and attractivity to mention some relevant goals, as shown by the work of Becker and Steele (1995), Horgen et al. (1999) and Grantham (2000), among others. A usability appraisal will focus on environments, in order to assess their efficiency and effectiveness. It is developed and used various methods for evaluating usability in buildings, for example Usetool (Hansen et al. 2009). Common methods include interviews, questionnaires to users and walk through observation (Harun et al. 2011). Overall, this type of tools provides a good picture of how users perceive one building. Big Data has potential to complement qualitative evaluation methods.

POE is designed to explore in a systematic way how far existing buildings fulfil the objectives of architectural design in reality, i.e., once they are occupied (Preiser et al., 1988). The purpose of POE is to collect information and develop knowledge on the impact that building design and construction decisions have in a long-term perspective. Such knowledge can be utilized for further improvements in the building industry. Steinke et al. (2010) point out that there is no industry-accepted definition of building evaluation, or a standardized method for doing evaluations. An important issue in usability appraisal is to acknowledging the particular setting and context of the study (Alexander, 2010). A usability appraisal will therefore focus more on the user experience, compared to a POE that is more likely to focus on the building.

For evaluation purposes it is not necessarily important to have extremely large amounts of data. Smaller volumes of quantitative data can also be an important contribution to evaluations. Experience from the collection and analysis of real large data sets are, however, relevant for quantitative analysis of small amounts of data as well. For some time, researchers in the field of usability have recognized the need for the development of methods that gives them quantitative data. Blakstad et al. (2008) states that: *“So far in our research, most of the research has been explorative, using qualitative methods, often case studies, as research strategies. For more descriptive and causal studies we will need to develop methods that give us quantitative data and defined indicators that may allow us to benchmark between multiple cases.”* (Blakstad et al. 2008, p 29). This is in line with findings from previous studies showing that evaluations work best when they are based on several methods and data sources (Frechtling, 2002).

3 APPROACH

The results are a summary of findings from literature search and interviews. There are few direct experiences from using Big Data in evaluations. We therefore had to identify applications of Big Data that are relevant to evaluation, and have potential for use in an evaluation context.

In the literature study we have primarily reviewed scientific articles and publications on Big Data, evaluation and usability. The literature on Big Data has covered a wide range of topics including technology solutions, legal issues, applications, innovation, etc. The purpose of the review was to map various aspects of the topic that will be relevant to the use of Big Data in the evaluation of newly build public buildings. Regarding facilities management, literature search was made on the term usability, but also on combinations of evaluation and Big Data with Facilities Management.

The empirical part of the study is based on interviews about the possibilities in using Big Data for evaluation of buildings in a FM perspective. We have interviewed eight IT-specialists, four specialists in FM and three governmental representatives. We conducted interviews with representatives from various organisations with activities related to, or with potential for use of, Big Data. We used a uniform semi-structured interview guide. However, in the interviews with IT-specialists focus came on technical solutions. In the same way, the interviews with FM professionals emphasised data availability and use of analyses and results. With the government officials, we addressed regulations and framework conditions for applications of Big Data. Most interviewees are representing Norwegian organisations, but several of the IT and FM professionals work in an international context. Within a week from the interviews we summarised the results from interviews in an internal memo. These memos were consulted in writing a case study report (in Norwegian). This paper is based on the case study report, with special emphasis on application of Big Data in a FM context. The case study report has also been subject to internal quality assurance from colleagues in the authors' organisations.

4 RESULTS

In the following, we present results from the study. Firstly, we comment on key issues regarding the use of Big Data in evaluation. These issues are availability, applicability, relevance, privacy, ownership, cost and competence. Secondly, we present different types of new data that may be used for evaluation of building usability.

4.1 Availability

The availability of data is controlled by two factors. First, someone must ask for the data. The interviews shows several examples of data that has been available but not used because no one saw the potential. The second factor is that data must be made available for analysis. There is an ongoing trend for disclosure of data. (FAD 2012) A challenge in many evaluation situations is to get data covering long time periods, and especially data describing the situation before a project starts. This could be many years back in time when an ex-post evaluation should be performed. The interviewees highlight that it may be necessary to take steps to ensure that data is stored over long periods of time, so that data is available in an evaluation situation. It requires that one is aware of the type of data that is relevant for an evaluation.

4.2 Applicability

Big Data creates new opportunities to analyse a phenomenon based on different types of data. The interviews illustrate that it is possible to find a set of indicators that are relevant in the evaluation. This should increase validity. In an evaluation context Big Data can be used to:

- Support triangulation and quality assurance of data
- Complement and enhance existing evaluation parameters
- Provide new evaluation parameters
- Provide quantitative data on the conditions previously been based on qualitative assessments
- Illustrate effects that have not been possible to visualize previously

Access to multiple datasets that illustrate the same phenomenon can be used for triangulation. Triangulation can include the use of established types of information, such as interviews and document, but also use of quantitative data, such as sensor data from different sources. We found several examples where sensor data from different systems and different measuring principles can be used to illustrate the same phenomenon. Triangulation can also be done based on completely different types of data, such as sensor data combined with internet data. Internet data can illustrate how people or the media portrays a new (or old) building.

4.3 Relevance

As pointed out by several of the respondents, Big Data is often collected in an unusual way for a statistician. There is a need for new statistical methods to understand data that is not perfect and not collected for statistical purposes, but still has the potential to be used. Traditional statistical issues such as representative population, significance and selection criteria must be adapted to new types of data. Another concern of the interviewees associated with the use of Big Data in evaluation is that the comparability over time can be difficult. These challenges can be reduced if the data is stored with the highest possible resolution and it stated clearly how the data are collected and processed. The relevance of the data and analyses may also be challenged by the use of aggregated data. If the variation within each group in the aggregates becomes too large, the relevance of the analysis can be questioned.

4.4 Privacy policy

Both from an ethical and legal point of view, it is important to protect personal information and respect people's privacy. This has been a concern in all interviews, although evaluators are typically not interested in studying individual users of a building. Rather, they look for user patterns. Privacy do not need to be an obstacle to the use of Big Data, although it seems to be the issue that people in general are most concerned about. All data that does not include personal information is basically unproblematic, both as individual data sources and the combination of several sources. Combination of different data sources, where there are persons who are the link between the various data is more problematic. Data from different sources with personal data can be combined without revealing personal information, but this can be challenging. Anonymity in datasets is typically achieved by aggregation, where each group includes so many persons that individuals cannot be identified. Another restriction is that in Norway, data should only be used for the purpose it was intended (defined prior to data collection). Our impression from the interviews is that when data is anonymised (for example aggregated) these restrictions do no longer apply.

The use of aggregated data is basically not a problem in research when one wants to uncover trends, patterns, etc. The same applies to an evaluation context. Privacy issues seem manageable, but require access to technical and legal expertise, which may result in additional costs. However, the interviews indicate that it may require that analyses must be done on less detailed data than would have been technically possible.

4.5 Ownership

The legal basis for ownership of Big Data appears to be somewhat unclear to the interviewees. Two principles that several of our interviewees mention are that (1) anyone who collected the data owns them and (2) aggregated data are owned by the person or organisation that did the

aggregation. Another important topic today, and especially in the future, will be control of the use of data. This includes issues such as “Who has seen and used a data set, and for what purposes?” The interviewees expect that future data management will not only relate to data collection, storage and analysis, but also to have reliable systems to manage the data use.

4.6 Cost

The interviewees highlight that cost for use of Big Data has been reduced as both storage and analysis capabilities have become cheaper and more accessible through the use of cloud-based solutions. Collection of data has become cheaper than before. Sensors are readily available, inexpensive, standardised and simpler in installation and operation. If the use of Big Data replaces established data sources, the overall costs are likely to increase, at least initially. The benefits of getting these data can still be large enough to justify the cost. In the event that Big Data can replace more time-consuming and costly data collection for evaluation, it represents an efficiency increase. One can thus do more evaluation for the same amount of money, or reduce the cost of evaluation.

We also note that there is an expectation that data will have a commercial value. But at the same time, the volume of open data is increasing. Competence for analysis and processing of data is also required, and a cost component itself.

4.7 Competence

Several of the interviewees, as well as Manyika et al. (2011), highlighted that available competence can be a limiting factor for the use of Big Data. This appears to apply to a FM contact as well. Skills are needed for identification of relevant data sources, for data collection, analysis and interpretation.

5 PRACTICAL IMPLICATIONS

5.1 Evaluating newly built public buildings using Big Data

For buildings that welcome the public, for example a museum, the experience of Big Data in the retail industry is relevant. The retail industry uses Big Data to analyse customer behaviour both at the aggregate and individual level. At the aggregate level, Big Data can help to identify which products are selling best in different locations and in different customer groups, both inside the store and between stores and regions. To do this, one summarises information about which the customers are, at what time they visit the stores, how they travel to the store, and about purchasing patterns for different customer groups. On the personal level, offers can be tailored to identify customers based on purchasing behaviour (Davenport 2012). In the evaluation of buildings it is mainly principles of the aggregate type of analysis that seems relevant.

It is necessary to distinguish between the construction and operation of the buildings and the activities carried out in the buildings. Those who build and maintain the building are typically concerned with the financial, technical and operational aspects of the building. Clients and customers who use the building are concerned that aspects of the building are affecting the business (for example, increased productivity and collaboration).

Conditions that are interesting related to building usability include:

- Where people are, where they congregate, meet
- Energy use and environmental factors
- Comfort Systems, open window, shield lights, turn on light, temperature, etc. in the building

There are various methods for evaluating usability in buildings. Common methods include interviews, surveys and questionnaires. Overall, this type of tools provides a good picture of how users perceive one building. Evaluation is still primarily based on how the building is used at the time of evaluation. There is a risk that the users involved in the evaluation are those that are specifically dedicated and examples are the most or least satisfied users. Big Data opens to add qualitative evaluation methods. Big Data illustrate the use of the building over a long period of time and can cover a wide range of users.

Recently, there have been published several examples of evaluation of buildings in use, using quantitative methods based on Big Data approaches. Yoshimura et al (2012) logged movement of Bluetooth devices (in practice smartphones) to describe how visitors move in the Louvre Museum in Paris. They contain movement patterns and length of visits. Rawassizadeh et al. (2011) used a camera to record the cleanness of an area. The cleanness was measured by recording changes in the colour intensity over time. They used the colour intensity on a clean surface as a reference. Khani et al. (2011) used special equipment to monitor eye movements. The purpose was to examine the relationship between eye movements and perceived comfort, especially related to different lighting conditions.

Operation and maintenance can be evaluated using new data. It has been done some quantitative evaluation of construction costs, and later evaluation of energy (ZEB 2013). Possibility to use data from different automation systems in buildings increases when such equipment become more common, the data are stored and new approaches to use these data are applied. In addition there is a development of IT systems for planning and monitoring operational and maintenance tasks. This is interesting data, which is now more readily available. But there is at least initially not data in such large quantities that they go under the definition Big Data, without making it less interesting information.

New types of data relevant to the evaluation of buildings include:

- Internet activity: Examples include how the current buildings are discussed on the Internet, Facebook, Twitter etc, how many Google searches are made on the building?
- Location data: how many are in an area in or near the building, time of day/week, where they come from and where they go. Can be based on GPS, mobile phones, access control systems, video cameras, or else.
- Sensors: Logging temperature in the building, the use of different automation systems (lighting, climate, energy), sensors that count the number of passages (into a room, for example)
- Behaviour: What do people do, such as which websites accessed from wireless networks in the building. Login on computers can be used to log the utilization of office jobs.
- Economic activity: Registrations with credit card - when, how people use money?

Table 1 illustrates how different types of Big Data can be utilised in relation to evaluation of buildings. The summary is based on the different Big Data categories.

Table 1: Illustration of use of Big Data in building evaluation

Category	Effect	Indicator	Data source	Availability	Applicability and relevance	Privacy and property rights
Internet activity	Usability	The experience of the building	Mention of the building on the Internet	No access	Relevance of high-profile buildings like the Opera	Not Personal Data
	Efficiency in operations	Type of Use	Websites that sought from the local network	Could be logged. Administrator for wifi system has access	Displays the type of internet activity to building users	Can not be linked to the device (PC, phone, etc.) used
Movements	Efficiency in business, usability	Where people are, their retention	Login at the local wifi network	Could be logged. Administrator for wifi system has access	Showing equipment using wifi / internet	Must be anonymised and / or aggregated
	Efficiency in business, usability	Movements, retention	Access cards	Not a tradition of handing out	Only applicable for areas with access control	Must be anonymised and / or aggregated
	Efficiency in business, usability	Where people are, movements	Video camera	Requires analysis of video	Showing activity where there is a camera	Depending on type of analysis
Physical Environment	Efficiency in business, usability	Use of the building	Light switches, motion sensors in rooms	Not a tradition of storing or handing out	Depends on the type and location of sensors	No personal data for public premises
	Operating Cost	Energy	Energy Management Systems	Store in part for mapping energy	Important cost	No personal data for public premises
	Efficiency in business, usability	Use of the building	Energy Management Systems	Store partially	The focus on energy consumption, but also illustrates the use	No personal data for public premises
	Usability	Indoor air	Air conditioning, CO measuring		Part of usability	No personal data for public premises
Commercial activity	Efficiency in operations	Number of users, type of use, revenue	Use of payment cards	Not a tradition of handing out	Important information for commercial premises	Privacy
Internal records / data	Operating Cost	Maintenance Activity	Operating and maintenance systems	Related info with the building manager	Shows the level of usage and kindness in technical solutions	Not Personal Data
	Operating Cost	Cost of operation and maintenance	Accounting system	Facilities manager may have this	Displaying cost, life cycle cost	Not Personal Data
	Operating Cost	Scope of modification	Area registry and accounting	Facilities manager may have this	Showing adaptability	Not Personal Data

In addition, table 1 gives some examples of relevant potential data sources, their availability, applicability and relevance. Finally, we give a preliminary judgement of the privacy issues involved. To be able to discuss the involved cost and needed competence, pilot studies are recommended. There are indications that tracking of locations and use of data from different building control systems has the largest potential for use in usability evaluations in the short term.

5.2 Reflections on practical implications

Our study has attempted to look into the various areas that are important for the potential use of Big Data in the evaluation availability, applicability and relevance, privacy and ownership, cost and competence. Privacy concerns, property rights and competence influence availability of data. We find that privacy and property rights are not necessarily an obstacle for the use and analysis of Big Data. The legislation and privacy concern does generate various challenges that influence the availability and use. It seems that the technological development has run in front of the

legislation. This applies to both national and to an even larger extent international legislation and guidelines. People with appropriate competence for research, data collection, analysis and visualization are a scarce resource and may limit the potential for use of Big Data both in Norway and internationally. Our impression is that the different types of Big Data probably have a major potential to be used in evaluations. In particular, several different data sets that illustrate the same phenomenon can be used for triangulation and quality assurance of facts evaluations. The utility can be somewhat reduced when data is available in many different formats.

Big Data creates new opportunities to analyse a phenomenon based on different types of data. This increases the opportunities for the evaluator to find indicators that are relevant to the building being evaluated. However, the applicability and relevance is challenged in at least two ways. One is that Big Data means a new way to deal with information and may require new use of statistical methods. Traditional statistical issues must be adapted to new types of data. The second challenge is the need for data covering a relatively long time period, typically a few years. We recommend that data is stored with the highest possible resolution and it is clearly described how the data are collected and processed. In addition, measures are taken to store data it is stored for long time periods.

6 CONCLUSION

Big Data is an area of rapid development. It has published a lot on the topic in general, and both practitioners and academics see opportunities. Much has been done in the private sector (including retail, business analysis), while the public sector appears to be somewhat behind. There are some published results related to an FM context, but it appears to be a potential for more FM applications in general. We have studied evaluations on buildings and usability. It seems to be great opportunities for using new (large) data in building evaluation. We have found several examples of creative use of Big Data relevant to usability evaluation, but few have explicitly used data from intelligent buildings to evaluate building usability.

We recommend pilot studies, where one tries to use various forms of Big Data in performing evaluations. A likely role for FM professionals is to contribute to the initiation of pilot projects by identifying appropriate measures, appropriate types of data, help in interpreting the data and putting them into an evaluation context. It is likely that we need assistance related to data acquisition and analytics. This is an area of very rapid development, and apparently with a large potential to move usability evaluation of buildings towards a new dimension.

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