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USE OF COGNITIVE MAPPING IN THE DIAGNOSIS OF TOLERANCE FAILURE

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The management of construction tolerances is a necessary and routine part of the construction activity and is normally brought to our attention only when failures are reported. In a study of tolerance management, the authors found widespread evidence of the same failures and the reasons for them. There seems to be no shortage of experience of the effects of failures in tolerances or of knowledge about how to avoid them. The situation is frustrating for all involved, especially the owner, end-users, designers and operatives. In questioning practitioner experts in this field, the authors identified a misalignment in the perception of 'problem, cause and effect'. In workshops involving experts from various construction backgrounds, the issue of tolerance management and, in particular, failures and their causes were examined. The experts were introduced to the concept of fault diagnosis using backwards-chaining 'cause and effect' analysis. Experts were then asked to undertake several analyses of their own of preselected failures using a cognitive mapping tool. The purpose of the study is to see how useful the method is among the experts and later be able to identify the root causes to the issues of tolerance management. The preliminary results showed that the experts were initially reluctant to break with discussing the effects and what they saw as the solutions, but gradually began to trace the causes backwards until they believed they had identified the root causes. The results show a possibility to reach beyond the obvious problems and therefore as a consequence be able to find a new approach in the following steps of the research process. This is a proven working method for research problems where the interaction with partners in the industry is of great importance.

KEYWORDS: Cognitive mapping, construction tolerances, failure

INTRODUCTION

This paper discusses a method put in practise for creating an understanding of the problems of tolerance management present in the construction industry. Complications due to misfits lead to delays, increased costs and lack of estimated performance. The problem has long existed and there is a need for a new approach and a new method for dealing with these complications. The difficulties to gather relevant data cause problems in the research process. The method denoted cognitive mapping is used as a general concept for investigating the root causes to previous identified problems.

There are a variety of standards, rules and regulations for how tolerances for various building components are determined. The fact is that there are many different values of tolerances, in the industry, resulting the emergence of problems. There are also different standards and regulations for different materials (Holm et. al. 1987, Meacham 2010). Which level of performance accuracy is required and what are the responsibilities to maintain the acceptable level of construction quality? Performance approaches have for several years been identified in building regulations, design and in various construction documents. Without adequate controls, education and feedback in the process, it is possible for problems to go unnoticed and to outpace solutions (Meacham 2010). Many times the meetings between different materials, construction nodes, can be complicated. It depends on the material behaviour, design, the manufacturer and the construction itself but there are also implications throughout the lifecycle of a building. Many problems that occur on the construction sites are mostly caused by the joints and connections between different building components. It is common that failures due to lack of tolerance management are adjusted on-sites (Landin and Kämpe 2007). Interface management within the construction process continue to cause problems. Therefore there is a need to understand the problems as early as possible in the process. Interface management for different components should be identified and verified to determine how they affect the entire project. This requires an understanding of the project structure among all participants (Pavitt and Gibb 2003, Yan et. al. 2009).

Specifications of construction tolerances on component dimensions can have impact on the quality, cost, and performance of the product. But a component cannot be manufactured exactly to nominal dimensions due to variations in human behaviour, materials and machines (Kumar et al. 2007). To eliminate this kind of problem the root causes need to be determined in the construction process. Is it possible to examine whether there exist tolerance abnormalities which are more frequent, or more expensive than others? When a tolerance deviation occur, it is also important to determine at which stage the construction process deviation occurs. Tolerances are divided into manufacturing tolerance, measuring on-site tolerance and assembly of a complex site tolerance (Holm et. al. 1987).

Occasionally, the failures have serious consequences, such as following a structural collapse. The causes are often quickly detected and more often than not are found to be rooted in a recognised problem. Despite considerable experience of failures due to poor definition of tolerances and the means for overcoming them, problems recur causing further damage and distress. Not all failures are as pronounced as a structural collapse and most tend to be accepted as ‘what might be expected in the course of construction work’. Evidence of such acceptance is to be found in innumerable examples of the same problem recurring. The steps that should have been taken to avoid them were known, yet they were not and the failure occurred. Furthermore most of the problems could have been solved already at the planning stage (Landin and Kämpe 2007). The resolution of the problems is in finding ways to ensure that the same mistakes are not repeated. It is not new for the industry that the cost of deviation is multiplied, the later in the construction process the deviation is discovered and can be addressed (Love and Irani 2003). Reference is generally made to the problem as the manifestation of a failure rather than the root cause. For owners and end-users, what is actually observed is the problem; but for designers and operatives it is the effect of a problem elsewhere. Cataloguing failures is common and the authors have been acquainted with many. There is no shortage of material describing and illustrating the consequences of failures. It is not always easy to understand where issues or problems may arise. Hence, there is a potential for improvement of the management of construction tolerances.

Background

The management of precision is one of the key foundations to the industrialized construction. Regular and accurate measurements are required to yield an effective production. Strategies concerning the technical approach to be taken in efforts to achieve greater industrialisation are directed increasingly at developing robust and standardised processes and procedures for the manufacture of products of different types, regardless of whether production takes place on-site or in a factory (Winch 2003, Johnsson and Meiling 2009). The precision in the construction industry does not mean zero tolerance for deviations, rather that the final product must meet the requirements and does not hinder the production process. It must also be possible to carry out the construction. All dimensions and part of dimensions of a building are interdependent. To achieve the coordination between function, safety and aesthetics, these parts need to be synchronised. More building components are constructed with traditional industrial technology and repetition of precast products for mass production.

The construction industry has a tendency to use audits only for correcting defects and not so much for further analysis. To get a better quality in construction, the defects should be linked to an improvement strategy (Johnsson and Meiling 2009).

The construction industry requires dimensional space dependent among others on the suitability and smoothness of different materials. Some materials do not have the ability to retain their qualities over time. The tolerances are degrees of accuracy and are also dimension describing a building element within certain limits (Ballast 2007). Tolerance levels are difficult to apply to different components within a building project as a whole. There are tolerance requirements dealing primary with concrete, steel, wood and glass. This can complicate the planning of how assembling material to another or joining of materials in the best way (Landin and Kämpe 2007). Tolerances are of significant meaning for managing quality. The management of tolerances became an important issue early on when the need for product efficiency increases. Recently the tolerance systems have also increased in importance as to gain customer satisfaction and also to avoid disputes to achieve production. The building must achieve the customer satisfaction by stated requirements of aesthetics, function and safety (Forsythe 2006).

With today's advanced technology, in terms of Computer Aided Design (CAD) and Building Information Model (BIM) development, there are great opportunities to minimize production tolerances and deviations, already during the design and manufacturing. BIM is a way to manage information produced during the design and construction process and a number of benefits and challenges have been identified. But due to incompatibilities among systems in the industry, technical obstacles have prevented integrated BIM. Many times the expected benefits of technological innovations do not guarantee the transfer and diffusion completely. To implement BIM in construction projects, some participants in the industry say it requires a cultural change in the industry. It says also that the applications requiring a more long term perspective in the production process (Linderoth 2010).

Tolerances are an important area in the building industry because tolerance management is important in different stages of the development of a product, stages like design, manufacturing, assembly and quality control. In the building process the tolerance transfer needs to be required. There are tolerance techniques as tolerance charting which is used in manufacturing industries. In order to set the tolerance accumulation, tolerance charting needs a dimensional chain describing method. The techniques of tolerance transfer make it possible to establish the inequalities of tolerance accumulation in a final dimension scheme of the product (Conzalez Contreras and Rosado 2006). But this requires that different parts in the construction process have good coordination and that the companies in the industry use the same system to coordinate all dimensional parts which is novel.

There are several different frameworks that are used to determine tolerances. Sometimes even the companies have their own, internal tolerances that they use. In addition, there are tolerance standards from older versions that are still used in the industry. The building industry consists of complex projects that are multi-organisational and required range of expertise. When the projects become increasingly complex and the traditional project management becomes inadequate, the methodological approaches must allow for a more detailed insight into the processes involved (Edkins et. al. 2007). The traditional project management must take into account the metrics of quality, cost, designs and time, which all are affected by the accuracy and precision in the building process. To get a better tolerance management in the process the issues need to be understood at a deep level among the experts in the industry why this research management tool, cognitive mapping, has been used. The current phase of the research involves a series of mapping sessions with individual experts using further examples.

METHODOLOGY

The study follows an inductive approach investigating tolerance failures. The method is a qualitative data analysis that strategically identifies the different causes which are dependant to each other. The participants are carefully selected people in the industry who have experienced the problem about the management of construction tolerances. The method denoted cognitive mapping is used as a general concept for investigating the root causes to previous identified problems. The aim of this method is to gather knowledge and views among the participants in the industry through workshops. Analysis over the causes which the participants raised can then be made. Furthermore correlation among the root causes can later be established and possible solutions to the problem can be found. This study focuses mostly on the use of cognitive mapping and not so much on possible solutions to the problem of tolerance management itself.

Cognitive mapping

The use of cognitive mapping has been a growing area of interest among the scientists. The technique or the method cognitive mapping has also been used and developed over a period of time. It has also been demonstrated its use for researcher working on a variety of different tasks. Mostly the technique have been used to structure messy or complex data for problem solving, managing large amount of qualitative data and assisting interview process. Cognitive mapping have been used for a variety of purposes but the concept “problem” of some sort usually forms the focus of the work. The technique is used to structure, analyse and make sense of accounts of problem. The process promotes the analysis, questioning and understanding of the data (Ackerman et. al. 1992 and Edkins et. al. 2007).

Cognitive mapping builds upon personal construct theory (Kelly 1963) and that of the repertory grid technique (Fransella et. al. 2004). According to the theory, individuals or groups, acquires codes and information about the relative locations and attributes of phenomena in their everyday environment (Downs 1973, Edkins et. al. 2007). This information is categorized as constructs representing the sum of perception of a specific phenomenon. Cognitive mapping may be defined as a process composed of a series of psychological transformations which is used to elicit those construct in a systematic manner. Therefore; the cognitive mapping techniques are used to identify the participants’ beliefs about a particular area or topic and to depict these diagrammatically. Cognitive mapping is an umbrella term for causal mapping, semantic mapping, and concept mapping, all encompassed by the term cognitive mapping, referring to mental models or schemata of an specific object, event or process. Different types of cognitive maps and mapping are defined with some latitude and overlap, depending upon preference and context. Cognitive mapping results in graphical structures to make sense of information but it also gives a structure of knowledge (Tolman 1948). The method of cognitive mapping is a structured process, focused on a topic or construct of interest, involving input from one or more participants, that produces an interpretable pictorial view of their ideas and concepts and how these are interrelated. As a result of this method a graphical representation will be presented. Within the graphical representation there are nodes (points or boxes) represent concept and links (arrows or lines) represent the relationships between the concepts. The concepts, and sometimes the links, are labelled differently on the map. The links between the concepts can be one-way, two-way, or non-directional. The concepts and the links may be categorized, and the map may show temporal or causal relationships between the concepts (Novak and Cañas 2008). It is then easier to see the overall structure and how each concept and causal relationships relate to each other.

By producing a representation of how the participants think about a particular problem or situation the method can act as a valuable technique for helping the researcher and the experts themselves to develop a solution to problem. The ability to structure, organise and analyse data and visualize this with graphical representations enable both the researcher and the experts/participants together to perceive their own mental models of the phenomena being studied. Thus cognitive mapping not only provide clarity for the researcher but it does also makes the experts aware of occurring schemata and enables them to react and find a suitable direction forward. This allows for cognitive mapping, in addition to being a data collection tool, to act as an action science (Argyris et. al. 1990) catalyst.

The graphical representation can be designed differently. Hierarchical structure depends upon the context and perspective from which one approaches the map. By analyzing the concepts on the top of the map the researcher are able to compare emergent value systems within the map as well as between different maps. Those value systems describe problem areas or specific goals from which the rest of the concepts in the map stem. Furthermore concepts can be categorized by its centrality. This allows for the identification of concepts being cognitively central to other surrounding concepts. Identifying those concepts is essential for exploring possible options towards change. By analysing the different clusters in the map it gives indications of where the nub of the issues may lie. It facilitates the examination of emergent topics and themes within the map causing the investigated problem (Eden and Ackermann 1998). In the hierarchical map there can be circularity or loops, which destroys the hierarchical structure of the map and make it harder to analyse the topic concept. It is sometimes difficult to determine what cause is and what effect is (Eden et. al. 1992). A thorough analysis will also permit the researcher to identify potent constructs. Those constructs typically affects more than one value system, or influence more than one cluster. Those constructs usually appear in the bottom of a hierarchical map, hitting the top concepts through many pathways throughout the hierarchy (Eden and Ackermann 1998). Identifying those constructs is essential to identify root causes, and to allow for the prioritizing of which concepts to deal with in order to create maximum change to the core problem. The analysing part should also show which details need to be more considered and which concepts need to be more developed. Through the process of explaining the ideas of how the concepts fit together the participants begin to get a better understanding of the problem and allows for the construction of a more detailed map (Ackerman et.al. 1992).

RESULTS AND ANALYSIS OF THE WORKSHOPS

In a workshop involving experts from various construction backgrounds, the issues of tolerance management and, in particular, failures and their causes were examined. The experts were introduced to the concept of fault diagnosis using backwards-chaining ‘cause and effect’ analysis. Examples of how this might be applied to tolerance failures in construction were shown. Experts were then asked to undertake several analyses of their own of preselected failures using a cognitive mapping tool. The preselected failures were about shortcomings or problems about the tolerance management in the building industry. Four workshops have been conducted. In each performed workshop, the experts draw a map of their analysis over the problem area. After some time there was a well conceived map. During the workshops the participants were divided into groups of 3-4 people in each group. This size of the group is considered to be good because everyone should be heard and at the same time be able to comment on each other’s ideas. It requires a certain number of participants to perform a well developed map over the common problem. Too few participants may not consider everything within the issue area and there is then a risk of missing essential parts. Too many people in one group leads to that someone may not be heard and become a spectator. In the performed workshops, the participants were able to see their ideas in context of others. Using this technique in group made the individuals’ thoughts captured in a common map. The ideas are also presented anonymously for the individual when the developed map is finished.

During the workshops, it was noted that the participants found it difficult to both use the guidelines to create a map and at the same time discuss the problem with the others in the group. Sometimes the participants gave up with the mapping and making straightforward notes which is not beneficial to the cognitive mapping. The participants went back to cognitive mapping exercise when they were guided by the facilitators. The guidance is important during the performance why there were facilitators during the whole workshop. When the facilitators noticed that the participants start to go wrong, their task was to lead them on the right path again without affecting their views or thoughts about the problem. The authors of this paper had their role as facilitators during the workshops. This kind of method and mentoring went well for the development of the mapping and how the participants worked throughout the exercises.

As results from the different workshops there are a numbers of maps representing different problems and the participants’ thoughts about these problems. The results from the method cognitive mapping can be analyzed in different ways. The groups were free to choose their own problems they wanted to analyze because this practise should also be a direct benefit for them. But still it is important that the main problems consider the area of tolerance management.

The maps offer an explicit statement of a phenomenon and have already proven to be useful in discussions with the experts, but also amongst the experts themselves. Moreover, the maps represent a shared understanding of what happens and can highlight where attention to root causes needs to be directed. The different maps give different views of the problem and can also be merge in different ways. By examining the different maps, some common concepts can be found. Concepts in these cases are causes to the main problem. The analysing of the maps will continue to find different clusters containing various sub-areas of the problem. It will also highlight similar root causes to the problem. By finding these causes possible solutions to the problem can be identified.

CONCLUSIONS

Different topics of analysis detailed above have been presented in the preliminary analysis of this paper. The current study is not extensive enough to make any final conclusions whether the analysis reach the expectations. This is only a part of the process to establish the validity of cognitive mapping in this research field. On a general note some limitations should be pointed out. The methodology suggested above allows for an epistemological approach studying different phenomena in its current context. Every effort in generalizability would not be conductive using the suggestions in this paper. Even so; it might be possible to use quantitative methods in corporation with variants of cognitive mapping in order to adhere to a more positivistic approach e.g. by using neural networks in order to quantify the maps.

With this said; the result show a possibility to reach beyond the obvious problems and therefore as a consequence be able to find a new approach in the following steps of the research process. This is a proven working method for research problems where the interaction with partners in the industry is of great importance. When the workshops were conducted, the basic approach was deemed to be sufficiently validated by these actions. The preliminary results showed that the experts were initially reluctant to break with discussing the effects and what they saw as the solutions, but gradually began to trace the causes backwards until they believed they had identified the root causes.

The resultant maps will be compared and merged and a qualitative analysis will be performed to determine if certain concepts are implicated in more than one type of failure and, if so, their relative influence. The maps offer an explicit statement of a phenomenon and have already proven to be useful in discussions with the experts, but also amongst the experts themselves. Moreover, the maps represent a shared understanding of what happens and can highlight where attention to root causes needs to be directed. When even more workshops have been performed, a pattern can be read from the common maps and further analysis can be done to find the final root causes of the problem.

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REFERENCES

Ackerman, F., Eden, C. and Cropper, S. (1992). Getting started with cognitive mapping, Young OR Conference, University of Warwick.

Argyris C., Putnam, R. and Smith, D. M. (1990). Action science, Jossey-bass, San Francisco.

Ballast, D. (2007). *Initiative on Dimensional Tolerances in Construction Surface Compliance Design Issues*, United States Access Board, webpage accessed 20-01-2011 at http://www.access-board.gov/research/tolerances/design.htm/

Conzalez Contreras, F. and Rosado, P. (2006). An alternative method to tolerance transfer for parts with 2D blueprint, *International Journal for Production Research*, **45** (22), 5309-5328

Downs, R.M. and Stea, D. (1973). *Cognitive maps and spatial behaviour: process and products*. Editors: Downs R.M. and Stea D, Chicago: Image and Environment, Aldine, IL (1973), 8–26.

Eden, C., Ackermann, F. and Cropper, S. (1992). The analysis of cause maps, *Journal of Management Studies*, **29** (3), 309-325

Eden, C. and Ackermann, F. (1998). *Analysing and comparing idographic casual maps.* In: EDEN, C. & SPENDER, J. C. (eds.) London: Managerial and organizational cognition : theory, methods and research. Sage.

Edkins, A. J., Kural, E., Maytorena-Sanchez, E. and Rintala, K. (2007). The application of cognitive mapping methodologies in project management research, *International Journal of Project Management*, **25** (8), 762-772

Fransella, F., Bell, R. and Bannister, D. (2004). *A manual for repertory grid technique*, Wiley: Chichester.

Forsythe, P. (2006). Consumer-perceived appearance tolerance in construction quality management, *Engineering Construction and Architectural Management*, **13**(3), 307-319

Holm, H., Lindberg, Å. and Lorentsen, M. (1987). *Projektera och bygga med toleranser* [Design and build with tolerances], Stockholm: AB Svenska Byggtjänst.

Johnsson, H. and Meiling, J. H. (2009). Defects in offsite construction: timber module prefabrication, *Construction Management and Economics*, **27** (7), 667-681

Kelly, G. A. (1963), *A theory of personality: the psychology of personal constructs*, New York: Norton.

Kumar, M. S., Kannan, S. M. and Jayabalan, V. (2007). Construction of closed-form equations and graphical representation for optimal tolerance allocation, *International Journal of Production Research*, **45** (6), 1449-1468

Landin, A. and Kämpe, P. (2007). Industrializing the construction sector through innovation – Tolerance Dilemma, Conference CIB 2007- 387, Cape Town, South Africa.

Linderoth, H. C. J. (2010). Understanding adoption and use of BIM as the creation of actor networks, *Automation in Construction*, **19** (1), 66–72

Love, P. E D. and Irani, Z. (2003). A project management quality cost information system for the construction. *Information and Management*, **40** (7), 649-661

Meacham, B. J. (2010). Accommodating innovation in building regulation: lessons and challenges, *Building Research and Information*, **38** (6), 686-698

Novak, J. D. and Cañas, A. J. (2008). The Theory Underlying Concept Maps and How to Construct and Use Them, Technical Report IHMC CmapTools 2006-01 Rev 2008-01, Florida

Pavitt, T. C. and Gibb, A. G. F. (2003). Interface Management within Construction: In particular Building Facade, *Journal of Construction Engineering*, **129** (1), 8-16

Tolman, E. (1948) Cognitive maps in rats and men. Psychological Review **55**(4), 189-208, American psychological association

Yan, C., Ruifeng, X. and Liqun, W. (2009). Geometric Tolerances Information Modeling for Integrated Manufacturing Processes, WASE International Conference on Information Engineering, Hangzhou Dizn University.

Winch, G. (2003). Models of manufacturing and the construction process: the genesis of re-engineering construction, *Building Research and Information*, **31** (2), 107-118