International Journal of Industrial Ergonomics 58 (2017) 90–108

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Identification and assessment of requirements of temporary edge protection systems for buildings

Guillermina Andrea Penaloza, MSc, Tarcisio Abreu Saurin*, Carlos Torres Formoso, PhD

Federal University of Rio Grande do Sul, Brazil

ARTICLE INFO

Article history:
Received 12 January 2016
Received in revised form
6 October 2016
Accepted 16 February 2017
Available online 11 March 2017

Keywords:
Temporary edge protection systems
Falls from height
Requirements management

ABSTRACT

Although the use of temporary edge protection systems (TEPS) is an important measure to prevent falls from height in construction sites, there is no comprehensive set of requirements for assessing those systems. Most assessments on TEPS are based only in structural requirements. This study proposed TEPS requirements from regulations, direct observations in construction sites, including TEPS assembling and disassembling operations, analysis of TEPS designs, and interviews with practitioners. Thity-three requirements were identified and divided into three categories: safety (14), efficiency (13), and flexibility (6). A protocol for assessing the requirements is also presented, and its use is illustrated by the evaluation of 9 types of TEPS in 26 construction sites. Both TEPS design and use are covered by those evaluations, which set a basis for discussing the theoretical and practical implications of this research study.

1. Introduction

Falls from height are widely known as a frequent type of serious accidents in the construction industry (Yoon and Lockhart, 2006). Some contributing factors commonly pointed out are the lack of collective fall protection barriers, ineffectiveness of some barriers, lack of workers' training, layout constraints (Hsiao and Simeonov, 2001), and the lack of consideration of prevention through design principles (Zhang et al., 2015).

Among possible fall protection measures, this research emphasizes the temporary edge protection systems (TEPS), which are usually necessary at least in some stages of most construction projects. This study is concerned with class A TEPS (hereafter, simply TEPS), which is defined by EN 13374 standard as the one that provides resistance to static loads only (AENOR, 2004). According to this standard, those TEPS should be designed based on requirements: to support a person leaning on the protection or provide a handhold when walking beside it; and stop a person who is walking or falling towards the protection. This TEPS plays an important role for the prevention of falls from the structure (other than roof) of buildings, which was pointed out in a study by Huang and Hinze (2003) as the second most frequent location of falls.

The TEPS's major advantage is its passive nature, which means that workers do not need to take any action for the system to have the desired effect after it has been installed properly, contrary to what occurs with personal protective equipment (PPE). The fact workers do not need to interpret physical barriers like TEPS is also desirable in workplaces where the safety culture is weak (Hollnagel, 2004), as often happens in construction sites.

While regulations define requirements associated with dimensions and structural integrity of TEPS, they neglect requirements related to the flexibility of those systems to adapt to different contexts as well as requirements related to the efficiency of the assembly and disassembly process. Thus, designing or selecting a TEPS only based on its compliance with regulations may be misleading. However, previous studies have not yet identified a set of relevant requirements for TEPS and therefore there are no comprehensive methods to evaluate these. As such, this creates difficulties for construction companies, manufacturers, and designers of that type of equipment. Earlier studies have been focused on the assessment of the structural integrity of TEPS (Bobick et al., 2010; Lan and Daigle, 2009), sometimes also involving the test of new materials (e.g. Manalo and Pac, 2017), possibly as a result of the focus on compliance to regulations that is often adopted in the industry. A similar emphasis on structural safety seems to exist for other safety equipment, such as supported scaffolds (Rubio-Romero et al., 2013).

Considering the aforementioned context, the question addressed in this research work is stated as follows: how to assess TEPS based on requirements that go beyond those defined by regulations? In order to answer this question, a protocol for

* Corresponding author.
E-mail address: saurin@ufrgs.br (T.A. Saurin).

http://dx.doi.org/10.1016/j.ergon.2017.02.005
0169-8141/

assessing TEPS was developed and tested by evaluating 9 types of TEPS in 26 construction sites in Brazil. Insights from the discipline of requirements management (RM) provided the main theoretical basis for developing the protocol. In ergonomics, RM has been little explored so far, regardless of some applications in the context of product design (e.g. Lottridge et al., 2011). However, RM raises relevant questions for designing TEPS and safety equipment in general – e.g. who are the clients? How to identify and classify their requirements?

The remaining of this paper comprises five sections. Section 2 presents an overview of TEPS regulatory requirements, and the steps of the RM cycle; these two topics form the theoretical background underlying this research. The research method is described in Section 3, in which the premises for developing the TEPS assessment protocol are detailed, as well as the steps for applying and evaluating those systems. Section 4 presents the results of the field studies, shedding light on how the data arising from the protocol application can be organized and analyzed. Next, the evaluation of the protocol based on practical and theoretical criteria is dealt with in Secton 5. Lastly, Section 6 summarizes the main contributions of the paper, limitations, and opportunities for future studies.

2. Background

2.1. Overview of regulatory requirements related to TEPS

Working at height can be defined as every activity performed over a certain limit (usually 2.0 m) from the lower level, where there is risk of falling (Brasil, 2014). Table 1 presents an overview of the TEPS's requirements defined by regulations from the United States (US), European Union (EU), Brazil, and Canada (CAN). In addition to the fact that those regulations focus on geometrical and structural requirements, it can be emphasized that: (i) there is no agreement in relation to the loads the TEPS must withstand; (ii) only the EU regulations prescribe procedures for carrying out laboratory tests of TEPS's structural integrity; (iii) some features of the TEPS, such as resistance of the mesh, are specified by some regulations and not by others; and (iv) none of the regulations makes it explicit the technical assumptions underlying requirements – e.g. why is a certain load required?

2.2. Requirements management

RM was originally conceived as an academic discipline concerned with the product development process of manufactured products (Pahl and Beitz, 1995). More recently, applications in software development have produced theoretical and practical advances (Zhang et al., 2014). In construction management, RM has received growing academic attention (Jallow et al., 2014) and the term briefing is often preferred over RM (Shen et al., 2004).

RM has four steps: (i) identification, (ii) analysis and prioritization, (iii) specification, and (iv) evaluation. These steps repeat cyclically, and partially overlap with each other, during the product development phase (Sommerville, 2007). The **identification** of requirements starts by identifying the clients of the product or service, since the requirements are intended to satisfy some type of client. In this study, the definition proposed by Whiteley (1991) is adopted, for whom clients are all those parts for which the product adds value, either external or internal to the organization. For the TEPS, the main internal clients are workers, both those who assemble and disassemble the TEPS (temporary users), and those protected by them over their production activities (end-users). There are also several external clients, such as labor inspectors, labor unions, and society as a whole, to the extent that the costs of accidents are absorbed partly by Social Security. Once the clients are identified, their requirements are identified by using different sources of information, such as interviews, questionnaires, brainstorming, document analysis, observation and regulations (Bray, 2002).

Requirements are conditions that qualitatively express the properties that a product must have in order to meet users' needs. In turn, criteria are either qualitative or quantitative specifications of the requirements, so that they can be evaluated as objectively as possible (ABNT, 2013). Ideally, the criteria should be measurable, understandable, achievable, testable, traceable, exclusive (Kotonya and Sommerville, 2000), and may be limited by restrictions (Parviainen et al., 2005).

In the **requirements analysis and prioritizing** step, these are examined in depth and the importance of each one is assessed (Sommerville, 2007). In this step, it is common to identify conflicting requirements (Bray, 2002), especially if there are many clients. It is necessary to identify the set of requirements that results in a final product with higher added value and that consider the needs of the most relevant clients (Huovila, 2005). During the **specification** step, design solutions must be produced to meet the requirements (Bray, 2002). Lastly, in the **evaluation** step, tests are performed to assess the effectiveness and efficiency of the solutions (Sommerville, 2007). These tests can be performed, for example, by using physical or virtual models.

3. Research method

3.1. Research approach

Design Science Research (DSR) was the methodological approach adopted. It is a way of producing scientific knowledge that involves the development of an innovative artifact to solve a practical problem, and simultaneously making a kind of prescriptive scientific contribution (Holmstrom et al., 2009). In this research study, the proposed artifact is a protocol (i.e. a method) for the assessment of TEPS. On the one hand, this artifact helps to solve the practical problem of how to evaluate TEPS and compare different alternatives. On the other hand, the process of developing the artifact allowed an in-depth understanding of the TEPS requirements, and how these could be categorized.

The contributions of this research study are also framed as typical outcomes of DSR (March and Smith, 1995), involving: (a) constructs, which are the concepts used to understand a problem or to devise a solution; (b) models, which are sets of statements expressing relationships among constructs; (c) methods, which are goal oriented plans for manipulating constructs so that the solution is achieved; and (d) instantiations, which operationalize constructs, models and methods – the realization of the artifact in an environment. These four outcomes are interrelated (March and Smith, 1995), and especially models and methods are potential theoretical contributions of prescriptive nature resulting from DSR (Lukka, 2003).

The development of the protocol for assessing the TEPS was divided into seven stages: (a) identification of requirements; (b) classification of requirements; (c) definition of a system for assigning scores for the different levels of compliance with the requirements; (d) definition of sources of evidence to assess each requirement and assign scores; (e) selection of TEPS and construction sites to be assessed; (f) practical assessment in construction sites; and (g) evaluation of the protocol.

3.2. Identification and classification of requirements: sources of data and data analysis

Several data sources were used to identify requirements and assessment criteria. Initially, both Brazilian regulations and codes of