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A taxonomy of tasks in dam cracks surveillance for augmented reality application

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***Abstract* — *Augmented reality is an advanced computational visualization technology that alters how users in the real world can perceive the virtual information. The use of this technology for EAC/FM is being widely investigated. In the scope of dam safety, the constant analysis of concrete behavior is mandatory, searching for clues of pathologies such as cracks. Cracks are relatively common in concrete structures, nevertheless they need to be surveilled due to the risks they offer. The surveillance of cracks involves exhaustive tasks, and for dams, it consists in the execution of a set of complex tasks that demands access to accumulated data and information. Augmented reality can contribute with the visualization process of this information, diminishing the mental workload demand. This paper defines a hierarchical taxonomy of the tasks that are needed in this domain, using Berliner´s taxonomy to classify the tasks, enhancing the understanding of the points where the augmented reality can be used with better results.*

Keywords— augmented reality, task-analysis process, crack surveillance, dam crack, taxonomy.

I. INTRODUCTION

Augmented reality is an advanced interaction and visualization technology that has been widely used in a variety of domains, including entertainment, tourism, and help with task execution. This technology improves your perception of the environment around. In EAC/FM, augmented reality has been widely used in all phases of the enterprise life cycle. It can help by presenting, in a contextualized way, project information, schedule, planning, historical data, allowing the user to keep his attention on the task he is doing, avoiding context change. Computer systems that use augmented reality technology offer advanced means of interaction and visualization. They seek to expand the human perceptual system by combining virtual information in the real environment so that it contributes to improving the conditions for accomplishing the tasks. Systems development is guided by an HCI project, resulting from a user-centered analysis. A good augmented reality system needs to know the environment where the tasks will be performed, the tasks and the users who will perform the tasks.

For the success of the employment of augmented reality in AEC/FM it is important to identify the tasks and understand the information, perceptual and cognitive process required. The proposed taxonomy seeks to aid this.

Employing augmented reality in the context of crack surveillance can help technicians to better perform the tasks required in the context. This article details the scope of the tasks, identifies and classifies them using Berliner taxonomy in order to map the perceptual, motor and cognitive components involved.

II. AUGMENTED REALITY IN AEC/FM

The use of augmented reality in the AEC/FM is being investigated approximately two decades ago. Much of the scientific work describes the development and use of prototypes and evaluates users' satisfaction with the experiences provided [1–14]. Some augmented reality prototypes focus on aiding in the monitoring or inspection of environments during construction [1,2,4–6,9]. Others for assembling aid [10,15–17], maintenance [18], for the execution of tasks that present uncertainties [19], for training [8,14,20], for remote execution of tasks [21]. Some scientific works have investigated the contributions of augmented reality in the management of a building [3,4,6], others assert that augmented reality may favor communication [6,10,22] and the safety of workers in the construction environment [6]. Several of these works already mentioned use the augmented reality in conjunction with the BIM - *Building Information Model*. There are also papers highlighting the benefits gained

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from the use of augmented reality to explore the structured information of BIM [11], there are those who point out that it allows the information about the building, designed in the office, to be accessed at the construction site, in a contextualized way.

Research indicates that the adoption of augmented reality in the area is an extended version of BIM because the technology addresses one of the key issues currently investigated in BIM: effective and efficient means to exploit highly integrated and organized information [11,23].

This set of scientific papers proves that the technology has a positive impact on the practices of the sector and that can help in solving existing difficulties in many ways. Among the studies analyzed there were descriptions of the use of augmented reality in the infrastructure sector. The system proposed by Fujiwara: ARLINER, uses the technology to assist the construction of containment dams, in hazardous access places (active volcano slopes), through the remote operation of machines [21]. Hammad, Garrett e Karimi defined a class of augmented reality applications called MARSIFT – *Mobile Augmented Reality System for Infrastructure Field Tasks* [24]. This paper presents, in a descriptive way, utilities of mobile augmented reality in the accomplishment of the necessary activities in the infrastructure constructions. The use of augmented reality to guide the movement of professionals to specific locations, to present evolution information related to monitoring or inspection activities, to communication between teams and to identify specific positions of interest through accurate tracking techniques is cited. The work of Zhou, Luo and Yang describes a case study for quality inspection in tunnels [25]. A model is retrieved and used to establish a virtual line that overlaps in the real environment allowing the assessment of structural safety through the measurement of differences between the model and the real environment view.

The use of augmented reality in conjunction with BIM seeks mainly to [26]:

• Reduce discrepancies between planned and executed solutions.

• Reduce inefficiency in communication among professionals involved in activities.

• Improve the perception and cognition of the professionals involved in decision making.

• Facilitate access to information related to activities.

• Improve the concentration and attention of the professional in the execution of the activities. This set of work shows that augmented reality is a technology with great potential in AEC/FM. It has proved adequate to enable access and sharing of information by the team of professionals who cooperate with each other. However, there are few studies that explore the use of augmented reality in infrastructure construction.

III. CRACKS MONITORING

The safety of a dam is maintained when its structural and operational integrity is preserved so that it satisfies behavioral requirements that seek to avoid failures in operation, dam and reservoir [27,28].

In the operation phase of a dam it is essential to carry out a periodic surveillance and maintenance program [29]. A hierarchical classification of dam safety processes can be seen in the Fig. 1.

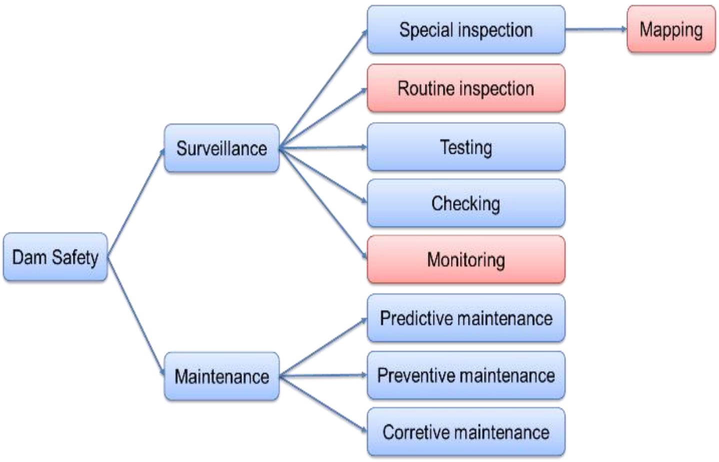

Fig. 1: Hierarchical classification of dam safety processes

Concrete behavior analysis occurs in the surveillance program; it investigates, among other things, the relationship of cracks with other dam events [30]. The presence of cracks in the structure is perceived during visual inspections (special, periodic or routine); however, in addition to identifying them, it is necessary to map them in order to understand the causative mechanism and the risks they pose to safety. Crack mapping consists of a thorough and exhaustive observation of the surfaces, in order to visually identify, record the shape and the relative location of cracks, according to some convention established by the organization. In addition, it is important to photograph and characterize cracks, building a historical record of its evolution over time. The records generate conditions to determine the cause and age of cracks [30].At each new mapping, a new set of individual data is collected. Although crack detection can occur in any type of inspection, it usually occurs only in special ones, where mapping is recommended. When a crack is identified, it has occurred some time ago. So it is not a simple task to make notes and estimates of the cause and age of the crack, but it is important to guide decision making. The data collected in the mappings need to be maintained to allow monitoring of evolution over time. The result of the mappings consists of internal and global reports, required by regulatory authority in the sector.

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They present the current condition and evaluate the behavior of cracks by comparison with previous results, which support recommendations and decisions regarding maintenance and installation of instruments to monitor the behavior of active cracks[30]. In addition, the set of information resulting from the mapping is necessary for conclusions about the security offered by the structure.

Although mapping inputs and outputs are well defined, there are several ways to do this, and their establishment in each organization considers, among other things, the size of the dam and the level of technology used in the context. The technologies employed directly interfere in the efficiency and in the effectiveness of the mapping.

IV. HIERARQUICAL TAXONOMY

Taxonomy is a term derived from the Greek (*taxis* - order and *nomy* - law, norm, rule) introduced by Candolle, in 1813 [31,32]. Initially, they were used to classify living beings in a logical and scientific way; but is currently a method used in varied contexts as a resource to organize and classify conceptual units [31].

In the context of information processing models, Berliner et al. [33], have proposed a taxonomy that determines elementary units of behavior in relation to perception, mediation , motor and communication processes.

The elementary units of behavior are declared by means of 32 verbs classified according to the type of activity performed. Although this taxonomy has been proposed more than 50 years ago, it is still used to determine human behavior and assist in describing operational procedures [34].

According to Eurocontrol [35] the classification proposed by Berliner et al. is useful to explain the behaviors that are common in tasks that require some type of interaction.

The elementary units of behavior classified according to the processes are shown in Fig. 2.

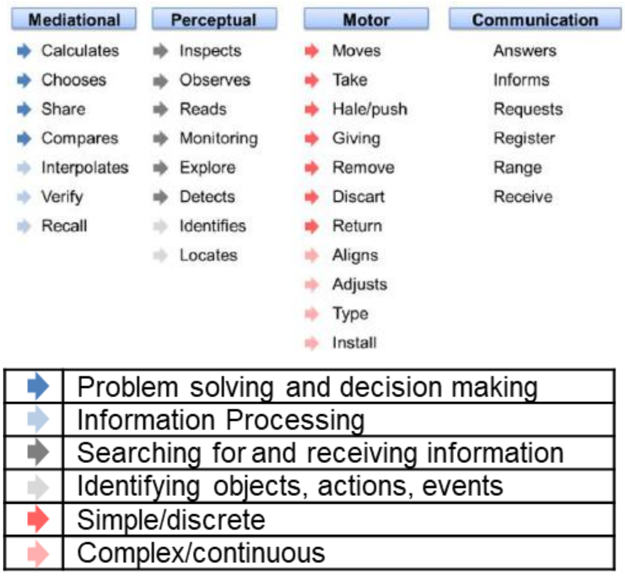

Fig. 2:Berliner's taxomony [34]

In the AEC/FM, taxonomies are used to classify the knowledge about the work required in the context so as to provide the means for the development of specific analyzes. Everett proposed a hierarchical taxonomy of construction-related tasks to analyze tasks and point out the most suitable ones for automation [36]. Everett's taxonomy is composed of nine *levels*: Industry, Sector, Project, Division, Activity, Basic Task, Motion, Orthopedics and Cell.

In order to analyze the tasks identified in the construction context, Everett took into consideration that humans are better able to perform tasks with predominance of improvised actions, or that have uncertain information and that require judgments based on experience and perception of complex stimuli. While machines are suitable for storing and retrieving information and performing repetitive jobs in a short time, without being distracted by external factors.

Dunston and Wang proposed another hierarchical taxonomy for the context of the AEC/FM [37]. In this case the operations and tasks were categorized. The main objective was to provide the conditions to analyze them on issues related to the use of mixed reality. According to the authors, the taxonomy provides the following benefits:

- It facilitates identifying the opportunities to explore the mixed reality in the AEC/FM.
- Establishes methodologies for mapping technology to context tasks.
- Identifies the core tasks of the AEC/FM.

This taxonomy proposed by Dunston and Wang is composed of five categories: Application Domain, Application specific operation, Operation specific activity, Composite tasks and Primitive tasks, as shown in Fig. 3.

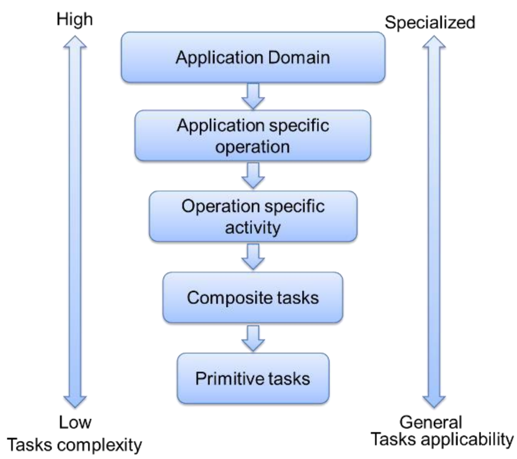

Fig. 3: Hierarchical taxonomy of AEC tasks and operations [37]

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According to the authors, the level of composite tasks is appropriate to assess the suitability of mixed reality technology and taxonomy evidences the needs of the practice required in the context, at different levels of complexity, by fostering the means to study them individually, and relating them to technology alternatives.

4.1. The proposed taxonomy

The proposed hierarchical taxonomy classifies the required work in the field of crack surveillance at five levels: Domain, Process, Activity, Sub-activities and Tasks, as shown in Fig. 4. It represents all the operational work required in the domain, which is composed of processes made through activities that are divided into subactivities; subactivities are composed of tasks performed to meet the needs of the domain.

Cracks surveillance is carried out through processes already consolidated in the context of dam safety, required by norms and laws that regulate and supervise the practices. The subset of the processes for surveillance of concrete dams that includes, among other things, the suveillance of cracks are: *Mapping*, *Periodic inspection* and *Monitoring*, as highlighted in Fig. 4.

Mapping is handled by the activities C*rack detection*, *Crack Characterization*, *Crack survey*, *Validate* and *Analyze behaviour*. On the other hand, the periodic inspection comprises the activities *Analyze Document*, *Anomaly detection*, *Crack Characterization*, *Crack survey*, *Analyze behavior* and *Validate*. Lastly, Monitoring occurs by means of activities: *Read instrument*, *Validate* and *Analyze behaviour*.

The proposed hierarchical taxonomy also has an intermediate level between the level of activities and the level of tasks, called Sub-activities. The sub-activities required in the activities are: *Surface inspection*, *Crack registration*, *Acquire location*, *Locate*, *Acquire openess*, *acquire length*, *acquire depth*, *Direction registration*, *Acquire image*, *Appearance registration*, *Age estimation*, *Cause estimation*, *Data examination*, *Data processing*, *Document examination*, *Advise*, *Send review*, *Develop report*, *Acquire reading*, *Routine inspection*, *Register event*, *Repeat reading*, *Check reading*.

At the last level of the taxonomy are the tasks to meet sub-activities: *Draw*, *Move to*, *Observe*, *Recognize*, *Photograph*, *Detect*, *Measure*, *Indicate*, *Annotate*, *Search*, *Research*, *Select*, *Prepare*, *Inform*, *Compare*.

The relationship between the elements of the taxonomy can be seen in Fig. 4. The links represented by dashed lines represent works that depend on specific facts to be performed.

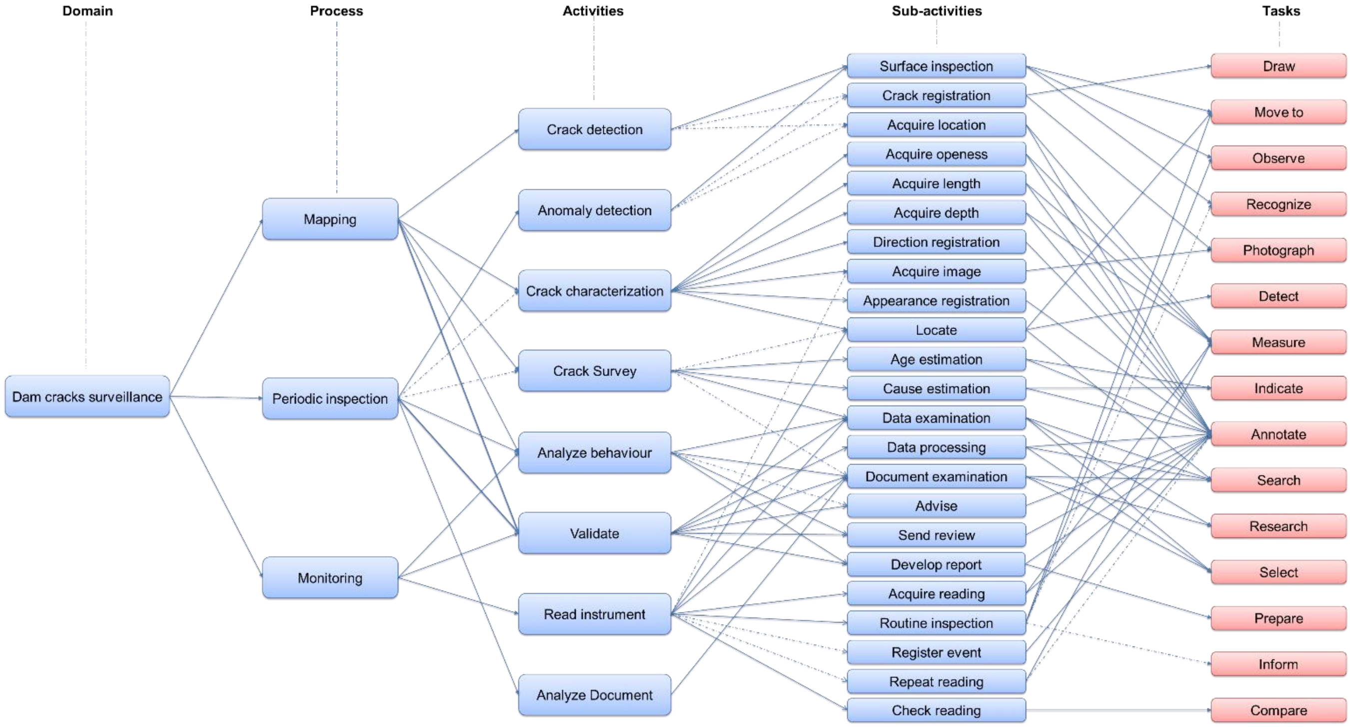

Fig. 4: Hierarchical taxonomy of tasks of the surveillance of cracks in concrete dams

4.2. Classifying tasks

Task is the smallest unit of work considered in the proposed taxonomy. It represents a portion of the physical work (interactions with the environment) and mental (internal interactions involving the perceptual and mediational system) that the user needs to perform in a sub-activity.

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The way in which the work happens depends on several extrinsic factors, such as characteristics of the environment where the task is performed and resources available to help the user execute them. The way the work happens depends also on factors intrinsic to the user, such as skills, experience and knowledge, among others. The tasks of the domain were classified according to the units of behavior of the taxonomy of Berliner et al., as shown in Table 1.

Table 1: Classification of the tasks of cracks surveillance in concrete dams on Berliner´s taxonomy

Tasks	Behavior	Process type
Draw	Register	Communication
Photograph		
Annotate		
Inform	Informs	
Move to	Moves	Motor
Observe	Observes	Perceptual
Research	Inspects	
Recognize	Identifies	
Detect	Locates	
Search		
Measure	Calculates	Mediational
Indicate	Verify	
Select	Chooses	
Prepare	Verify	
Compare	Compare	

V. CONCLUSION

There are several studies demonstrating the potential for augmented reality in the AEC / FM area. Existing solutions already explore augmented reality functions to optimize the activities in which they are applied. However, there is still room for research that seeks to broaden the understanding of both augmented reality technology and the domain to which these interfaces will be applied. The proposed hierarchical taxonomy and classification of tasks regarding Berliner taxonomy provides resources to identify the tasks with the greatest impact by using the technology. Since augmented reality is a technology that allows information access and visualization, it is concluded that structuring the knowledge about the perceptive, cognitive and motor workload of the tasks of the domain, allows the application of technology in a more conscious way, increasing the contributions provided by the augmented reality, favoring the successful application of the technology in the surveillance of cracks in concrete dams.

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REFERENCES

[1] Golparvar-Fard M, Asce M, Peña-Mora F, Savarese S, Asce M, Peña-Mora F, et al. Integrated Sequential As-Built and As-Planned Representation with Tools in Support of Decision-Making Tasks in the AEC/FM Industry. J Constr Eng Manag 2011;137:1099–116. doi:10.1061/(ASCE)CO.1943-7862.0000371.

[2] Golparvar-Fard M, Peña-Mora F, Savarese S. D4AR-A 4-Dimensional Augmented Reality Model for Automating Construction Progress Monitoring Data Collection, Processing and Communication. Electron J Inf Technol Constr 2009;14:129–53.

[3] Irizarry J, Gheisari M, Williams G, Walker BN. InfoSPOT: A Mobile Augmented Reality Method for Accessing Building Information Through a Situation Awareness Approach. Autom Constr 2013;33:11–23. doi:10.1016/j.autcon.2012.09.002.

[4] Kwon O-S, Park C-S, Lim C-R. A defect management system for reinforced concrete work utilizing BIM, image-matching and augmented reality. Autom Constr 2014. doi:10.1016/j.autcon.2014.05.005.

[5] Bae H, Golparvar-Fard M, White J. High-Precision Vision-Based Mmobile Augmented Reality System for Context-Aware Architectural, Engineering, Construction and Facility Management (AEC/FM) Applications. Vis Eng 2013;1:3. doi:10.1186/2213-7459-1-3.

[6] Park CS, Kim HJ. A framework for construction safety management and visualization system. Autom Constr 2013;33:95–103. doi:10.1016/j.autcon.2012.09.012.

[7] Park CS, Lee DY, Kwon OS, Wang X. A framework for proactive construction defect management using BIM, augmented reality and ontology-based data collection template. Autom Constr 2013;33:61–71. doi:10.1016/j.autcon.2012.09.010.

[8] Schwald B, Schwald B, DeLaval B, DeLaval B. An Augmented Reality System for Training and Assistance to Maintenance in the Industrial Context. 11th Int Conf Cent Eur Comput Graph Vis Comput Vis 2003:425–32. doi:10.1007/11941354_29.

[9] Shin DH, Dunston PS. Evaluation of Augmented Reality in steel column inspection. Autom Constr 2009;18:118–29. doi:10.1016/j.autcon.2008.05.007.

[10] Wang X, Truijens M, Hou L, Wang Y, Zhou Y. Integrating Augmented Reality with Building Information Modeling: Onsite construction process controlling for liquefied natural gas industry. Autom

Constr 2014;40:96–105. doi:10.1016/j.autcon.2013.12.003.

[11] Wang X, Love PE. BIM + AR: Onsite information sharing and communication via advanced visualization. Proc 2012 IEEE 16th Int Conf Comput Support Coop Work Des 2012:850–5. doi:10.1109/CSCWD.2012.6221920.

[12] Meža S, Turk Ž, Dolenc M. Component based engineering of a mobile BIM-based augmented reality system. Autom Constr 2014;42:1–12. doi:10.1016/j.autcon.2014.02.011.

[13] Wang X, Dunston PS. Compatibility issues in Augmented Reality systems for AEC: An experimental prototype study. Autom Constr 2006;15:314–26. doi:10.1016/j.autcon.2005.06.002.

[14] Dunston PS, Asce AM, Wang X. Mixed Reality-Based Visualization Interfaces for Architecture , Engineering , and Construction Industry 2005:1301–9.

[15] Reinhart G, Patron C, Reallty A. Integrating Augmented Reality in the Assembly Domain - Fundamentals, Benefits and Applications 2002.

[16] Hou L, Wang X. Experimental Framework for Evaluating Cognitive Workload of Using AR System for General Assembly Task. Proc 28th Int Symp Autom Robot Constr 2011:625–30.

[17] Hou L, Wang X. A Study on the Benefits of Augmented Reality in Retaining Working Memory in Assembly Tasks: A Focus on Differences in Gender. Autom Constr 2013;32:38–45. doi:10.1016/j.autcon.2012.12.007.

[18] Lee S, Akin Ö. Augmented reality-based computational fieldwork support for equipment operations and maintenance. Autom Constr 2011;20:338–52. doi:10.1016/j.autcon.2010.11.004.

[19] Su X, Talmaki S, Cai H, Kamat VR. Uncertainty-aware visualization and proximity monitoring in urban excavation: a geospatial augmented reality approach. Vis Eng 2013;1:2. doi:10.1186/2213-7459-1-2.

[20] Wang X, Dunston PS, Skiniewski M. Mixed Reality Technology Applications in Construction Equipment Operator Training. 21st Int Symp Autom Robot Constr 2004.

[21] Fujiwara N, Onda T. Virtual Property Lines Drawing on the Monitor for Observation of Unmanned Dam Construction Site. ACM Int Symp Mix Augment Real - ISAR 2000:101–4. doi:10.1109/ISAR.2000.880932.

[22] Shrahily RY, Medjdoub B, Kashyap M, Chalal ML. Communication framework to support more effective onsite construction monitoring 2015;149:195–203. doi:10.2495/BIM150171.

[23] Behzadan AH, Dong S, Kamat VR. Augmented Reality Visualization: A Review of Civil Infrastructure System Applications. Adv Eng Informatics 2015;29:252–67.

[24] Hammad A, Garrett Jr. JH, Karimi HA. Potential of Mobile Augmented Reality for Infrastructure Field Tasks. Seventh Int. Conf. Appl. Adv. Technol. Transp., United States: ASCE Press; 2002, p. 425–32. doi:9780784406328.

[25] Zhou Y, Luo H, Yang Y. Implementation of Augmented Reality for Segment Displacement Inspection During Tunneling Construction. Autom Constr 2017;82:112–21. doi:10.1016/j.autcon.2017.02.007.

[26] Chi H-L, Kang S-C, Wang X. Research Trends and Opportunities of Augmented Reality Applications in Architecture, Engineering, and Construction. Autom Constr 2013;33:116–22. doi:10.1016/j.autcon.2012.12.017.

[27] Brasil. Lei No. 12.334, de 20 de Setembro de 2010. . Brasília, Brasil: 2010.

[28] ICOLD. Dam Safety Management : Operational Phase of the Dam Life Cycle - Bulletin 154. Paris: CIGB - ICOLD; 2013.

[29] ICOLD. Dam Surveillance Guide - Bulletin 158. Paris: ICOLD; 2014.

[30] ICOLD. Concrete Dams - Control and Treatment of Cracks - Bulletin 107. Paris: CIGB - ICOLD; 1997.

[31] Currás E. Ontologias, Taxonomias e Tesauros em Teoria de Sistemas e Sistemática. Brasília: Thesaurus; 2010.

[32] Vignoli RG, Souto DVB, Cervantes BMN. Sistemas de organização do conhecimento com foco em ontologias e taxonomias. Informação E Soc 2013;23:59–72.

[33] BERLINER DC, ANGELL D, SHEARER J. Behaviors, Measures and Instruments for Performance Evaluation in Simulated Environments. Symp Work Quantif Hum Perform 1964:277–96.

[34] Begosso LC. S. PERERE - Uma Ferramenta Apoiada por Arquiteturas Cognitivas para o Estudo da Confiabilidade Humana. USP, 2005.

[35] Eurocontrol. Technical Review of Human Performance Models and Taxonomies of Human Error in ATM (HERA). Brussels, Belgium: Eurocontrol; 2002.

[36] Everett JG. Construction Automation: Basic Task Selection an Development of the Cranium. Massachusetts Institute of Technology, 1991.

[37] Dunston PS, Wang X. A Hierarchical Taxonomy of AEC Operations for Mixed Reality Applications. Electron J Inf Technol Constr 2011;16:433–44.