

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

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: ARLNER, 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.

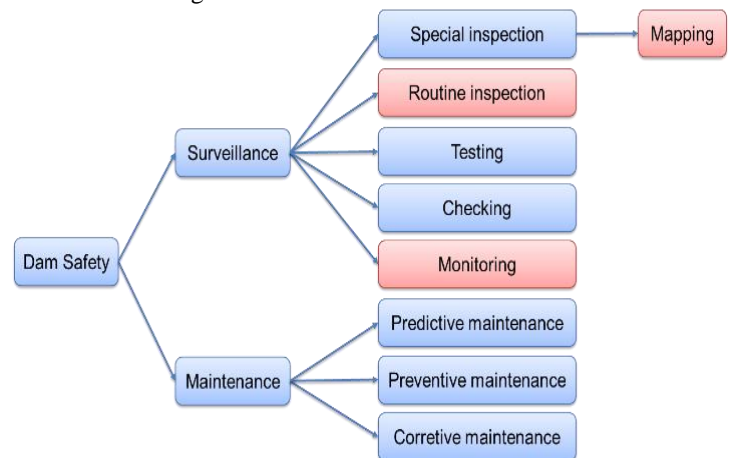


Fig. 1: Hierarchical classification of dam safety processes

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.

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. HIERARQUIAL TAXONOMY

Taxonomy is a term derived from the Greek (*taxis* - order and *nomos* - 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.

Mediational	Perceptual	Motor	Communication
Calculates	Inspects	Moves	Answers
Chooses	Observes	Take	Informs
Share	Reads	Hale/push	Requests
Compares	Monitoring	Giving	Register
Interpolates	Explore	Remove	Range
Verify	Detects	Discart	Receive
Recall	Identifies	Return	
	Locates	Aligns	
		Adjusts	
		Type	
		Install	

➔	Problem solving and decision making
➔	Information Processing
➔	Searching for and receiving information
➔	Identifying objects, actions, events
➔	Simple/discrete
➔	Complex/continuous

Fig. 2: Berliner's taxonomy [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.

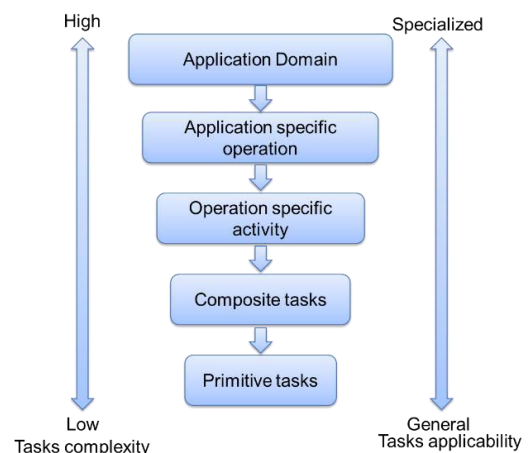


Fig. 3: Hierarchical taxonomy of AEC tasks and operations [37]

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 surveillance of cracks are: *Mapping*, *Periodic inspection* and *Monitoring*, as highlighted in Fig. 4.

Mapping is handled by the activities *Crack 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 behaviour* 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 openness*, *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.

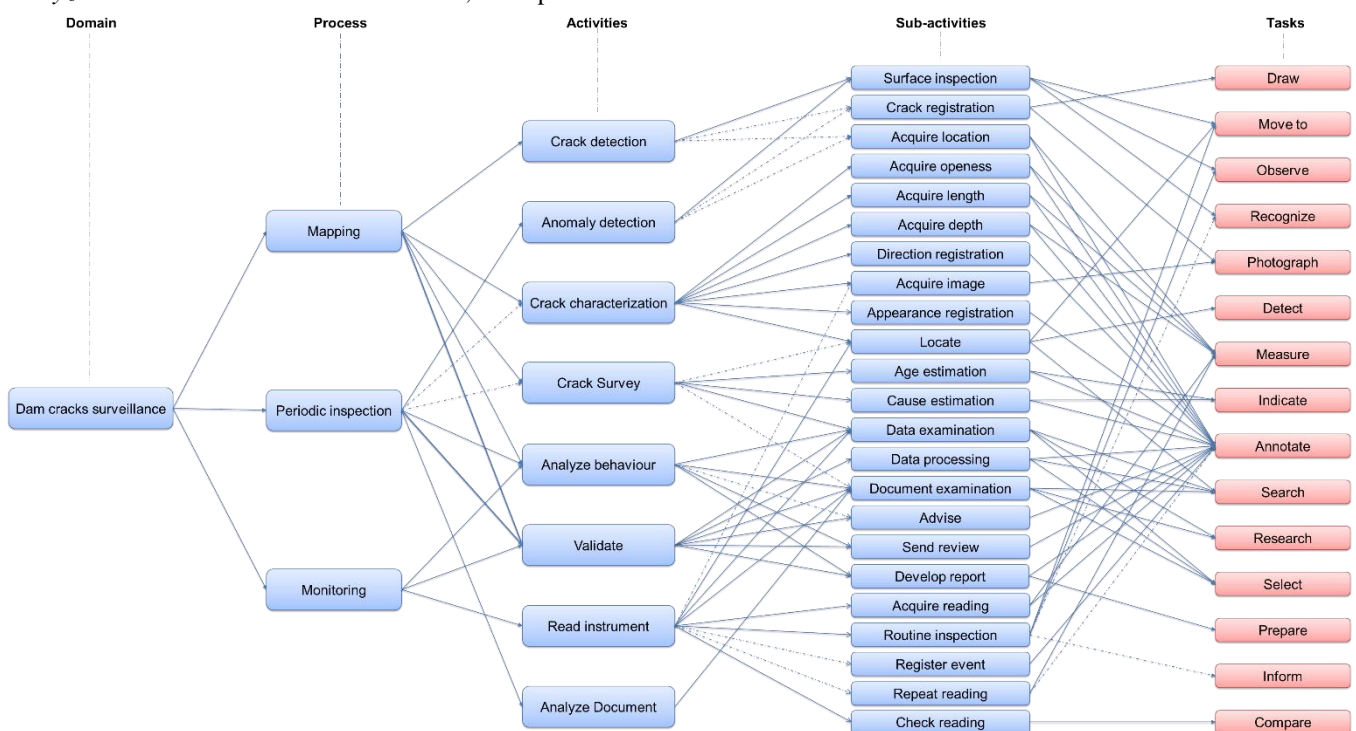


Fig. 4: Hierarchical taxonomy of tasks of the surveillance of cracks in concrete dams

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.

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	Motor
Move to	Moves	
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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