Aggregate heterogeneous knowledge about civil engineering failures by means of ontology to improve practices

Hoang Quynh Anh[1], Denys Breysse[1], Franck Taillandier[1], Cédric Baudrit[2]

[1] *Univ. Bordeaux, I2M, UMR 5295, F-33405 Talence, France*
quynh-anh.hoang@u-bordeaux.fr, d.breysse@i2m.u-bordeaux1.fr, franck.taillandier@u-bordeaux.fr
[2] *Univ. Bordeaux, INRA-I2M, USC 1368, F-33405, Talence, France*
cedric.baudrit@u-bordeaux.fr

RÉSUMÉ. *Les ouvrages de génie civil sont régulièrement confrontés à des problèmes résultant de défauts de conception ou de construction, d'une mauvaise utilisation, de vieillissement et de détérioration, et d'aléas naturels (tempête, séisme, etc.). Afin de prévenir et d'atténuer les accidents et les défaillances, il est nécessaire de réaliser des enquêtes et des analyses des défaillances passées (incident, accident, effondrement, etc.) pour en déterminer les causes. La connaissance des causes doit permettre d'en tirer des leçons permettant aux concepteurs et constructeurs ou fabricants de développer des alternatives plus sûres et de faire progresser leurs pratiques. Pour mieux comprendre et appréhender l'enchainement des événements menant à une défaillance afin de proposer des préconisation, nous présentons, dans cet article, un modèle générique de défaillance d'ouvrage basé sur une ontologie élaborée à partir de l'analyse des connaissances du domaine et sur la collecte de cas de défaillance. Il permettra de modéliser tout type d'ouvrage, de mettre en avant les éléments pouvant être source de défaillance et ainsi d'améliorer leur fiabilité. Un exemple tiré d'un cas réel de défaillance d'un ouvrage permettra d'illustrer le modèle.*

ABSTRACT. *Civil engineering works often copes with many problems as the result of design deficiencies, construction defects, misuse, aging and deterioration and environmental hazard such as storm or earthquake… In order to prevent and mitigate accidents and failures, investigation and analysis of past failure are required to determine the causes. Knowledge about cause should allow designers, builders and infrastructure managers to learn lessons in order to develop safer alternatives and to improve their practices. To help the cause analysis and the proposition of recommendation, we present, in this paper, a generic model of construction failure based on a specific ontology, build from domain knowledge analysis and past failure case collection. It allows to model any kind of structure, to highlight potential failure causes and to improve structure reliability. An example of a real failure case will be used to illustrate the model.*

MOTS-CLÉS : *Ouvrage de génie civil, Gestion des risques, Défaillance, Ontologie, Ingénierie forensique*.

KEY WORDS: *Civil engineering works, Risk management, Failure, Ontology, Forensic engineering.*

1. Introduction

Risk and uncertainty are inherently present in construction project and during civil engineering work exploitation. Failures could introduce huge impacts; for instance, the Malpasset dam failure in 1959 killed 423 people in the resulting flood. The failure of engineering structures is influenced by many reasons, not only technological problems but also social and natural events. The failures result in extensive damage and disruption to infrastructure and building. Structural safety therefore can become a major concern for workers and users. Gaining the appropriate experience and knowledge and turn it becomes a risk management knowledge system is necessary to predict, prevent, and manage risk in construction.

Risk management plays an important role in project management. The purpose of the risk management is to identify potential problems before they occur so that risk handlings activities can be planned and invoked as needed across the life of the product or project to mitigate adverse impacts on achieving objectives. There are some strategies to respond to a risk: avoidance, transfer, mitigation, and retention. In which, to avoid the risk is a good strategy when a risk has a potentially large impact on the project. Risk can frequently be avoided if their root causes are identified and managed before the adverse consequence – the risk event – occurs [SMI 06] Therefore, engineering investigation and determination of the causes (known as forensic engineering) of structural failures of buildings, bridges and other facilities is a solution to avoid and reduce the failures. Our challenge is to develop a holistic knowledge model from expertise and data of investigations about accidents in order to form recommendations for improving practices.

Ontology allows a formal conceptualization of knowledge. In the construction industry, the application and studies on ontology have been undertaken in risk-relevant domain [SHI 14] [DIN 16] [LIU 16]. It has offered a way to semantically represent and reuse domain knowledge. Most of research relates to application of ontology to develop a model or framework to enhance risk management performance in some contents such as cost overrun, heal and safety risk… There is little research in using ontology in construction failure. The focus will be given in this article to develop a general ontology on failures of civil engineering works based on expert knowledge and data gathering from construction accidents leading to a structuring model of knowledge and being able to be instantiated. Through this ontology, data is analyzed, causes are identified and lessons are identified to prevent structural accidents and improve construction practices. The model developed will enable a wide diffusion of this failure-related knowledge to anybody (experts, engineers, stakeholders…) interested in safety issues and risk management in construction project. Finally, we will present the use of this model to a real construction failure.

2. Ontology tool

Ontology is a structured representation of domain knowledge, which defines a hierarchic organization of concepts and relations that exist between them with rules and axioms, which constrain them. An ontology is then composed of concepts, relation rules, axioms and a lexicon allowing to reference concepts and relations. An ontology with a set of individual instances/elements of classes constitutes a knowledge base [NOY 01]. The ontology can be used to:

- To share common understanding of the structure of information among people or software agents
- To enable reuse of domain knowledge
- To make domain assumptions explicit
- To separate domain knowledge from the operational knowledge
- To analyze domain knowledge

Ontology enables to share information and to facilitate the communication as well between machines as between humans and machines. Building an ontology dedicated to the structure failure, is highly interesting to analyze failure and to learn lessons from them.

However, failure is a dynamic process which can be described as a chain of causes-consequences with multiple interactions; for instance, an error in the design of a structural element of a building coupling with an unexpected quantity of snow could lead to the collapse of the building. To describe temporal relations between events, which lead to the failure, time ontology is used with content of linking time and events. The OWL-time ontology adds temporal relations [ALL 04] enable to provide the ordering of events that had happened as for instance: 'before', 'start', 'during', etc.

3. Generic model

The gathering and analysis of information from literature, expert of the field and collection of past failures, allow us to build a generic model, which will be used to represent and investigate civil engineering structure failures. The proposed model, which is based on the time ontology framework, describes the failure but also the civil engineering structure itself. Indeed, we consider that the failure cannot be totally investigated without the understanding of the structure and its environment. The generic model contains 7 main entities (see fig. 1):

- Structure: type of structure (dam, building, etc.)
- Component: the different elements, which compose the structure (foundation, wall, beam, etc.)
- Function: role of the component for the structure (ensure water tightness, support the roof, etc.)
- Activities: action, which enable to build and maintain component (design, implementation, etc.)
- Organization: stakeholders, which have a role in the structure life (client, contractor, etc.)
- Environment: element outside the structure but having an impact on it (weather, neighborhood, etc.)
- Event: event that lead to failure (corrosion development, flood, etc.)

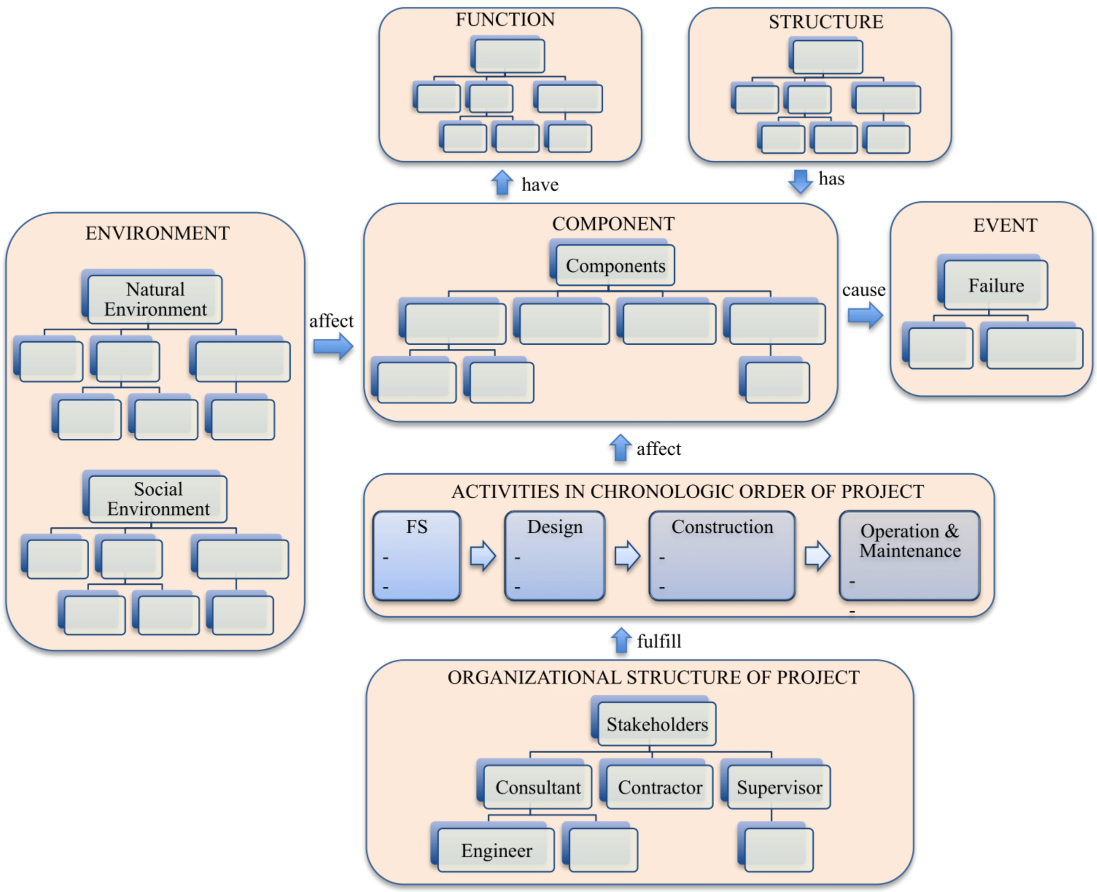

Figure 1. *Generic model*

The model formalizes the different entities and their relations. This model can be instantiated to represent any kind of failure on any kind of structure. However, it is limited by the exhaustiveness of the knowledge base, i.e. the list of entities and relation in the model. This work is still on-going and the knowledge base focuses for the moment only on dam but could be easily extended.

4. Application on real case: ST. FRANCIS dam failure

In order to illustrate the generic model on a failure case study, we instantiate it regarding the St. Francis Dam. It was a 205-ft high concrete gravity-arch dam constructed by the City of Los Angeles between 1924-26. It failed catastrophically on March 12, 1928, killing at least 431 people, making it the worst American civil engineering failure of the 20th Century [ROG 07]. Figure 2 displays the instantiated model corresponding to this failure. The seven main entities of the generic model were instantiated and enabled to formalize the failure process facilitating its interpretation by a human and by the machine. This last point is really important to automatize the development of new knowledge through the study of similarity between cases. For instance, it enables to investigate risks on a dam by comparing its element (component, environment, etc.) with dam impacted by failures from the database.

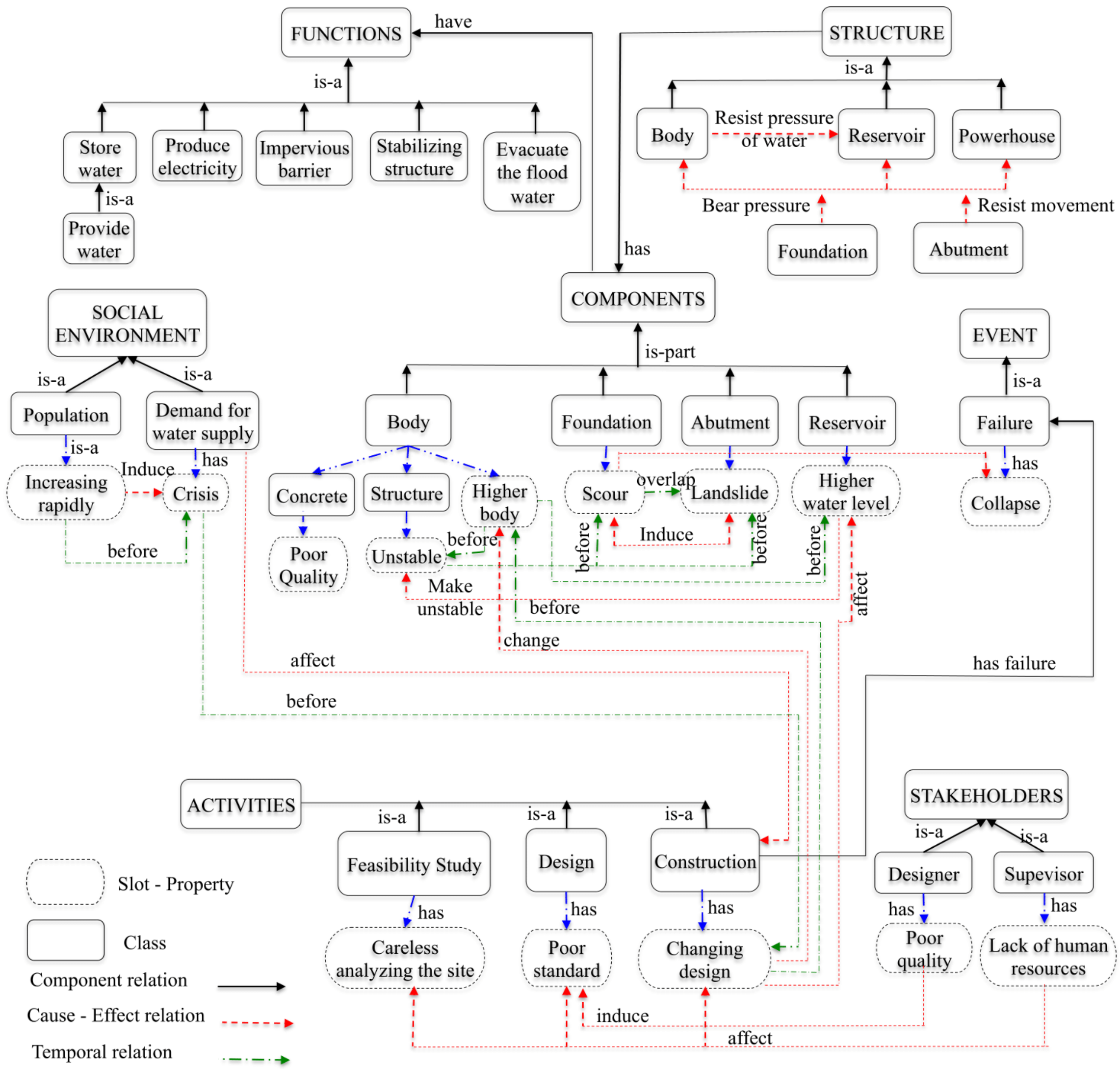

Figure 2. *Failure model of ST. FRANCIS dam.*

5. Conclusion

This research aims to develop a time ontology on the failures of civil engineering works based on data gathering from construction accidents and organizing follows a taxonomy and relationships between instances. Through this ontology, (1) data are analyzed, (2) causes are identified and (3) lessons learned are formed to help to prevent structural accidents and improve construction practices. Simultaneously, the possibility to approach information of construction failures is also widely available for all professionals who concern and interested in safety issues and risk management in construction project.

This study has provided the methodology for building an ontology describing a general model of construction failure. The following work is to develop a tool or an interface to make it available for approaching widely for all professional who are interested in construction failures and risk management. The knowledge base must also be extended in order to cover any kind of structure.

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