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A Framework for an artificial intelligence controlled seismic structural design system using ontologies and SysML

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Abstract

The assessment and design of structure resilience under earthquakes have been a major concern for structural experts, and researchers have made improvements in terms of analytical methods, theoretical models, failure criteria, seismic reliability, and damage assessment. However, with increased knowledge sharing and collaborative work within the civil engineering industry, there is a growing interest in cross-disciplinary, multi-objective and holistic approaches to resilience design over single effort to improve structural resilience previously. Ontologies and the semantic web belonging to symbolic artificial intelligence are currently advantageous in organising multi-source information and automated data exchange, while the graphical system modelling language SysML is a state-of-the-art system tool for designing interdisciplinary tasks. However, civil engineering professionals have little exposure to knowledge engineering and systems engineering and lack the foundation to build joint work. This study therefore proposes a framework based on ontologies and SysML for a fully machine-controlled structural seismic system. Through ontologies, SysML graphical workflows, AI code and artifacts, we can construct command streaming that understands semantics, actively searches and bridges different disciplinary contexts, giving computers a simulated sense of autonomy to understand and perform cross-domain tasks without human intervention. The proposed architecture, when applied to multidisciplinary involvement in structural resilience design, allows the AI to control and integrate isolated seismic components

and further explore the design space. This facilitates a breakthrough from rigid and stereotypical seismic designs and may end up with an overall better solution.

Keywords: seismic design, artificial intelligence, ontology, systems modelling language, SysML, automation workflow.

1 Introduction

The seismic design of buildings, bridges and infrastructures are always a key concern in civil engineering. Several research directions have been stimulated on how to improve the resilience of structures under earthquakes, including energy dissipation and vibration control [1], topology optimisation [2], structural intervention [3], reliability design [4], ultra-high performance materials [5], novel dampers [6] and energy harvesting [7]. These studies involve in knowledge and tools from different fields to expand the scope of resilience design greatly, which brings a forward-looking insight. Can the integration of the contributions of different disciplines lead to a multi-disciplinary, holistic resilience design of a seismic structural system? Further, can this seismic system, created from a holistic perspective, be autonomous adapted to different hazard scenarios?

With the development of artificial intelligence (AI), the above idea has a basis for implementation gradually. Ontologies and the semantic web are part of symbolic artificial intelligence. Ontologies formalise domain knowledge and knowledge associations into vocabularies of terms [8], while the semantic web written on the basis of description logic and web ontology language (OWL), provides a common framework that allows data to be shared and reused across application, enterprise, and community boundaries [9]. Ontologies are popular in fields that require large amounts of information organisation, sharing and reasoning (e.g. the biomedical domain [10]), and the semantic web has been widely used in information search and interaction on the Internet. System modelling language (SysML) is a method for graphically modelling the details of system architectures, and gives computability to graphical processes by linking them to external simulation software [11]. In a 2019 US defence project, researchers combined ontology and SysML to create a digital model of a drone, and achieved a preliminary multidisciplinary optimisation under AI control [12].

This paper presents a theoretical vision of using ontologies and SysML models to construct an autonomous AI-controlled seismic structural system that aggregates the best earthquake resistant components from different domains to obtain a dynamically optimal holistic resilience design. This research provides a practical guide towards smarter seismic design and offers a new insight into how AI can be used in multi-domain systems.

2 Methods

The AI-controlled seismic structural system consists of four layers: 1) a complete information model of the structural system expressed in the ontology; 2) SysML-written analysis workflow diagrams based on the ontology data; 3) the external simulation tools to execute the SysML graphical workflows; and 4) a platform to act as the AI-controlled centre. See Figure 1 for the overall architecture.

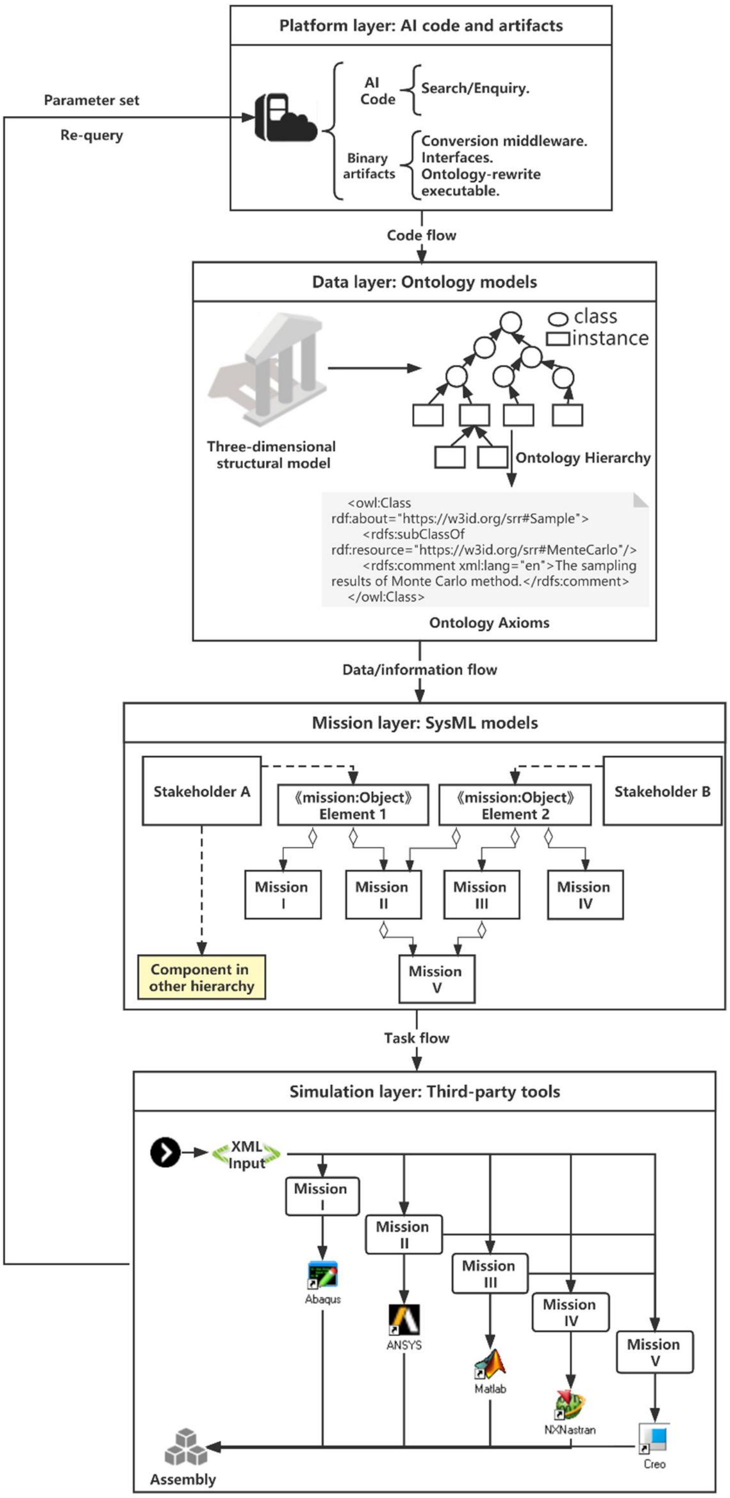

Figure 1: Overview of AI-controlled seismic structural system.

A realist ontology [13] for a three-dimensional structural model is generated from the instances already present in the model (beams, columns, brace, damping), from the bottom up producing ontological class assertions and finally forming the ontological hierarchy. This information organisation way enables standardisation and interoperability: machines avoid misinterpretations when exchanging data by consulting a common vocabulary; standardisation in turn leads to consistent terminology across domains, which can be used in the context of different disciplines to provide interoperability [10]. In practice, ontologies often use resource description framework (RDF) [14] or OWL [15] format, which are based on eXtensible markup language (XML), to enable machines to understand the data transfer between Internet applications. Ontologies can be reasoned and queried by computers.

The SysML models expresses graphically how we use the ontology data and information to accomplish the assessment of different seismic performance. This layer consists of two steps: 1) mapping the terminology and instances in the ontology to the classes and components of the diagrams in the SysML model, and 2) creating activity and analysis diagrams based on just acquired classes and components according to different seismic performance requirements.

The rich and diverse requirements defined by SysML must be connected to external simulation tools via interfaces to be truly executed. Software ModelCenter [16] provides the integration of simulation tools such as ABAQUS, ANSYS and MATLAB with SysML tools. The SysML tool MagicDraw has also developed a plug-in called Cameo Simulation Toolkit [17] that includes third-party tools such as Modelica, MATLAB and Maple.

The platform is the AI-controlled centre that is responsible for understanding the activities in the seismic structural system, automatically engaging analysis processes and coherently performing cross-platform tasks. Firstly, all documentation, models and AI program code are machine-accessible and machine-readable since they are not written in natural language and are not stored locally. Secondly, the platform is more likely to be a cloud server than a software. Cloud service providers like Docker, Amazon AWS, and Microsoft Azure support to deploy platforms/services in a distributed, more lightweight (requiring less memory) approach.

3 Results and Discussion

In this section we discuss the system characteristics and corollaries that result from the design philosophy, including data-driven design, AI-controlled automatic design and life-cycle design.

Data-driven design is driven by the ontology as a complete information model. When ontologies become the unified database for system tasks, multidisciplinary analysis processes under the ontology-based system will lead to a problem mathematically, called puzzles for solving multi-dimensional spaces for optimisation, which had been developed in the optimisation field for many years before the advent of ontology application in engineering. Now with the introduction of ontologies, we can conduct trade-off between different disciplines and use the optimisation results as an exploratory force to generate optimal structural designs in turn (because computers can automatically rewrite ontologies). This data-driven design is also known as 'generative design' used in the fields of parametric architecture increasingly [18] and topology optimisation, e.g. the computational structural design software Creo [19].

AI-controlled automatic design is due to the system framework built by ontology and SysML, which are machine-accessible and machine-readable. It is clearly written in the AI code that machine actively searches and queries the ontology and take actions following the SysML model guide. However, AI is not a real human being and there is no real spontaneous machine thinking [20]. We imagine using ontologies, graphical workflows and code to build command streaming that can understand semantics, search actively and bridge the contexts of different areas, to ultimately make the computer 'autonomously aware' as it appears.

Finally, real-time safety assessments based on measured data can be carried out along with the AI-controlled automatic design. The previous discussion desired to obtain a structural design solution that considers multidisciplinary seismic resistant factors prior to construction, therefore the ontology model is not changed after the design is complete. Whereas once the time factor is considered, for example the automatic conversion of earthquake sensor data (CSV or Excel) into ontological formats (RDF or OWL), the computer can identify new external condition through querying ontology and initiate a new phase of simulation, to determine whether the structure is safe. The AI-controlled system architecture thus contributes to the realisation of a flexible seismic monitoring system throughout the life-cycle of a project, from early design to operation and maintenance.

4 Conclusions and Contributions

Seismic design of structures should be regarded as a series of systematic design tasks encompassing seismic reliability, energy dissipative elements, topology optimisation and high-performance material applications. Integrating cross-domain results to generate a better holistic resilient design seems unrealistic since each task has isolated design objectives and incompatible analysis processes. This paper proposes a vision to achieve such a goal, based on recent advances in knowledge engineering and systems engineering.

An ontology is used as the complete information model for the whole system, responsible for linking heterogeneous data from different disciplines and providing no ambiguity cross-domain data exchange. The SysML graphical modelling language is used to construct separate activity diagrams for various analysis requirements based on the ontology data. These graphical workflows guide the computer finish the defined seismic analysis requirements without human intervention. Some commercial software already links third-party simulation tools such as ANSYS with SysML models, thus enabling autonomous machine control from the underlying data layer, mid-level requirements layer to the top-level simulation layer. Finally, a cloud server and AI code create the control platform for the entire system, which will run autonomously and flexibly to search for ontological information and perform disciplinary analyses, and to obtain the cross-domain optimal seismic design in an intelligent optimisation manner.

The new vision combines the benefits of knowledge engineering, systems engineering and cloud computing. Knowledge engineering (ontologies) is increasingly used to break domain barriers of complex systems and to enable the standardised sharing of data and semantics. Besides, ontology formats like RDF or OWL are machine-readable, so that ontologies can be used in machine controlled automated information exchange. Systems engineering (SysML) has the natural property of integrating multidisciplinary tasks and is dedicated to designing better complex systems to support better product design. Cloud computing offers another option, and large tasks in complex systems do not have to be done locally.

One of the contributions of this study is to propose a course of action to break the disciplinary isolation in seismic design by using computer-intelligible language, and thus to explore a larger design space integrating seismic components from different fields. On the other hand, our proposed AI-controlled architecture is a way to increase the awareness of computer autonomy, and it is a beneficial attempt to mitigate stereotypical thinking in structural design.

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