Integration of building and environmental data for fire emergency response operations

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About me

PhD Researcher at Trimble, Nov 2020

- Joined Trimble as a part of a PhD training program within the CBIM network.
- Assisting in a Product Owner role since May 2023

Academic Background

- MSc in Structural Engineering (**Thesis**: Incorporating BIM into the workflow of structural engineers)
- Phd in Civil Engineering (On-going), Technische Universität Berlin
  - **Research topic**: Integration of building and environmental data

Professional Background before Trimble

- Structural engineer at a design Firm
- Lecture and Academic research assistance at two universities
- Some experience in programming (Developed two applications in previous employment)

Research Motivation: Fire Emergency Response

- Fire hazards lead to more casualties than many other types of disasters (Coppola, 2015)

- Firefighters:
  - ✓ Safeguard occupants
  - ✓ Reduce property damage
  - ✓ Protect themselves
- Availability and quality of **data is critical**

Data Needed by Emergency Service Providers

- **Data** is **needed** for:
  - Routing and navigation
  - Assessing the hazard
  - Determining required resources
  - Utilising building safety features
  - Identifying potential hazards to firefighters
  - Post-incident analysis

Challenges of Acquiring Data

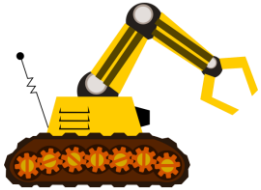
- Unknown environment
- Mentally stressful & physically demanding work
- Limited visibility
  - High reliance on signs
- Paper based data sources
  - Outdated & static
- Destressed civilian
  - Human error
- Complexity of structures

Research Gap

- Prior research focus on investigating information sources

Building Information Models

Sensors



Ground uncrewed vehicles

Extended reality gadgets

Geographic Information System

Personal protective equipment

Aerial uncrewed vehicles

Research Gap: Data Exchange Challenges

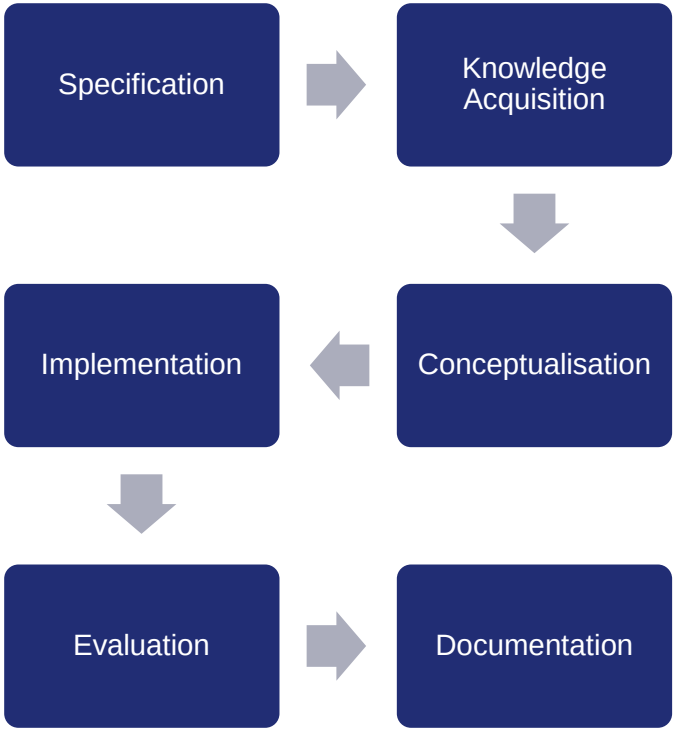
- Only a limited number have addressed the integration of information technologies (Weidinger, 2022).
- Firefighters are divided into multiple units
  - Exchange of data between these teams is required
- Firefighters interact with other emergency service responders (police, paramedic,…)
- Lacking a **consistent nomenclature** for referring to different concepts hinders communication during emergency response efforts (NFPA, 2018).
- Most equipment utilized in response operation exhibit **limited interoperability** among one another (Hamins et al., 2014)
- Integration between information technologies presents a significant challenge since they originated from different domains.

Research Questions

*How can a **formal**, **well-defined**, and **shared** understanding of the building fire emergency response domain be established?*

- Ontologies can be used to develop a **formal** and **structured** description of **shared** knowledge within a particular domain (Noy and McGuinness, 2001).
- Shared understanding enhances **communication** among individuals and organizations and promotes **interoperability** between systems (Uschold and Gruninger, 1996).
- Introduced A novel ontology: **Firefighters' Data Requirement Ontology** (Guyo et al. 2023)

Ontology Development: METHONTOLOGY (Fernandez, Gómez-Pérez, and Juristo 1997)



Specification

Domain: Building fire emergency

Purpose: Representing knowledge related with firefighters information needs.

Scope: The focus is on data about an affected building, its different components, and its surrounding.

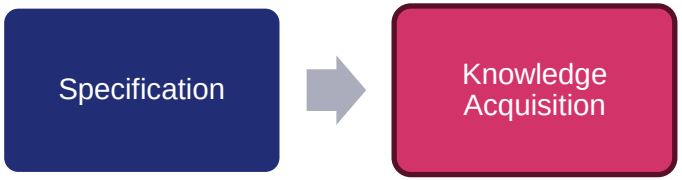
Intended use:

- Facilitate the **data exchange** process between different organization involved in emergency response as well as **interoperability** between systems used in the domain.
- A basis for developing new information systems for the domain.
- To develop ontology-based **data checking systems** for building and city datasets

Competency Questions

- What information about an affected building is required by firefighters to decide how much resource is required?
- Which environmental features at an incident site can interfere with firefighters' actions?
- Which building and environmental features can cause injury to firefighters?
- What information about fire suppression equipment (such as fire hydrants) is needed in order to operate them?
- What are the building safety systems that can support firefighters and how can they be controlled?
- And more

Knowledge Acquisition



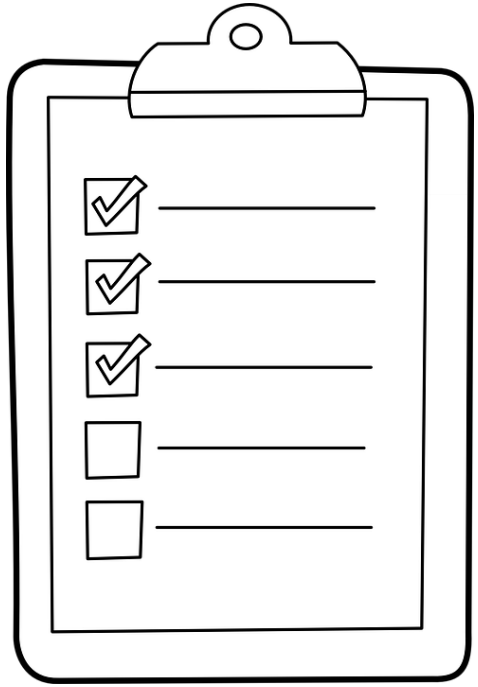
Knowledge Acquisition

International codes	The international building code (ICC, 2018a) The international fire code (ICC, 2018b) NFPA 1620: Standard for Pre-Incident Planning
Scientific papers	Jones et al. (2005) (Workshop with 25 first responders), Li et al. (2014) (Workshop with 29 first responders) Heron et al. (2003), Isikdag, Underwood and Aouad (2008), Ghodrat et al. (2021), Santarpia et al. (2019),
Manual	Occupational safety and health administration (2015)

Answers to Competency Questions

- Data about the affected building that is relevant for firefighters' operations, such as building occupancy, construction type, building height, and the number of stories.
- Data about any potential hazards in the building and its surroundings, such as chemical storage, gas tanks and powerlines.
- Data about different building and environmental fire suppression equipment that firefighters use such as fire hydrants, fire department connections, standpipes, fire hose connections, and fire pumps.
- Data about different building fire protection and suppression systems, such as fire alarm systems, automatic sprinkler systems, and smoke control systems
- And more

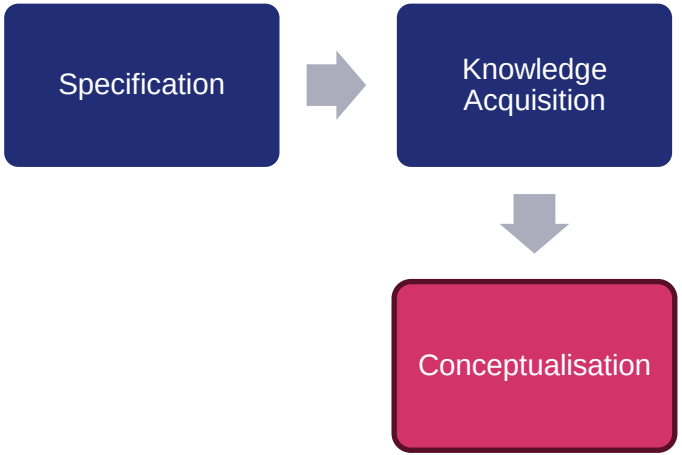
Knowledge Acquisition



Glossary of Terms

- Terms that should be included in the ontology.

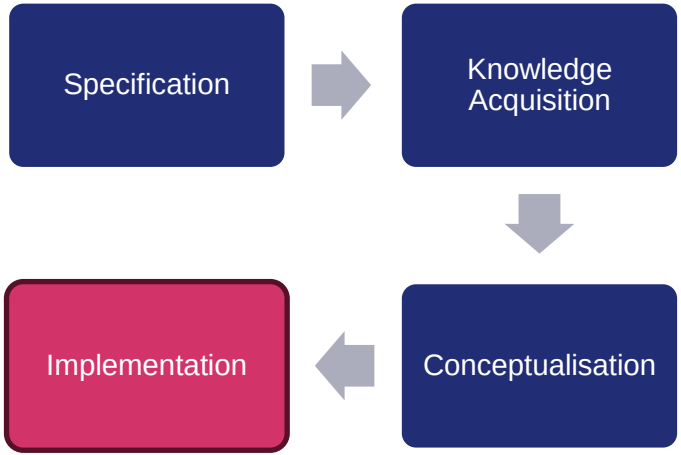
Conceptualisation



Conceptualisation

- Structure the gathered domain knowledge in a **conceptual model.**
- Terms that identify an object – **Classes**
- Terms that describe an object - **Properties**.
- Classes structured based on their **relationship**
- International codes are used to generate concise and consistent **names.**

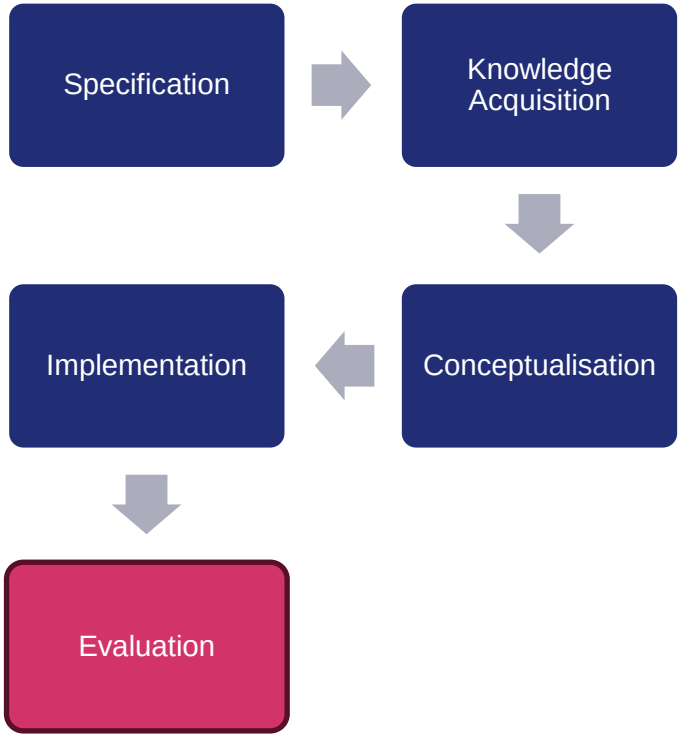
Ontology Development



Implementation

- Implementing the ontology in a formal language.
- The **web ontology language** (OWL) was used
- **Protégé 5.5.0**, was used as the development environment to create the OWL file.

Ontology Development



Evaluation

Verification

- Confirms the correctness of an ontology
  - Protégé Resoners
  - OOps!

Validation

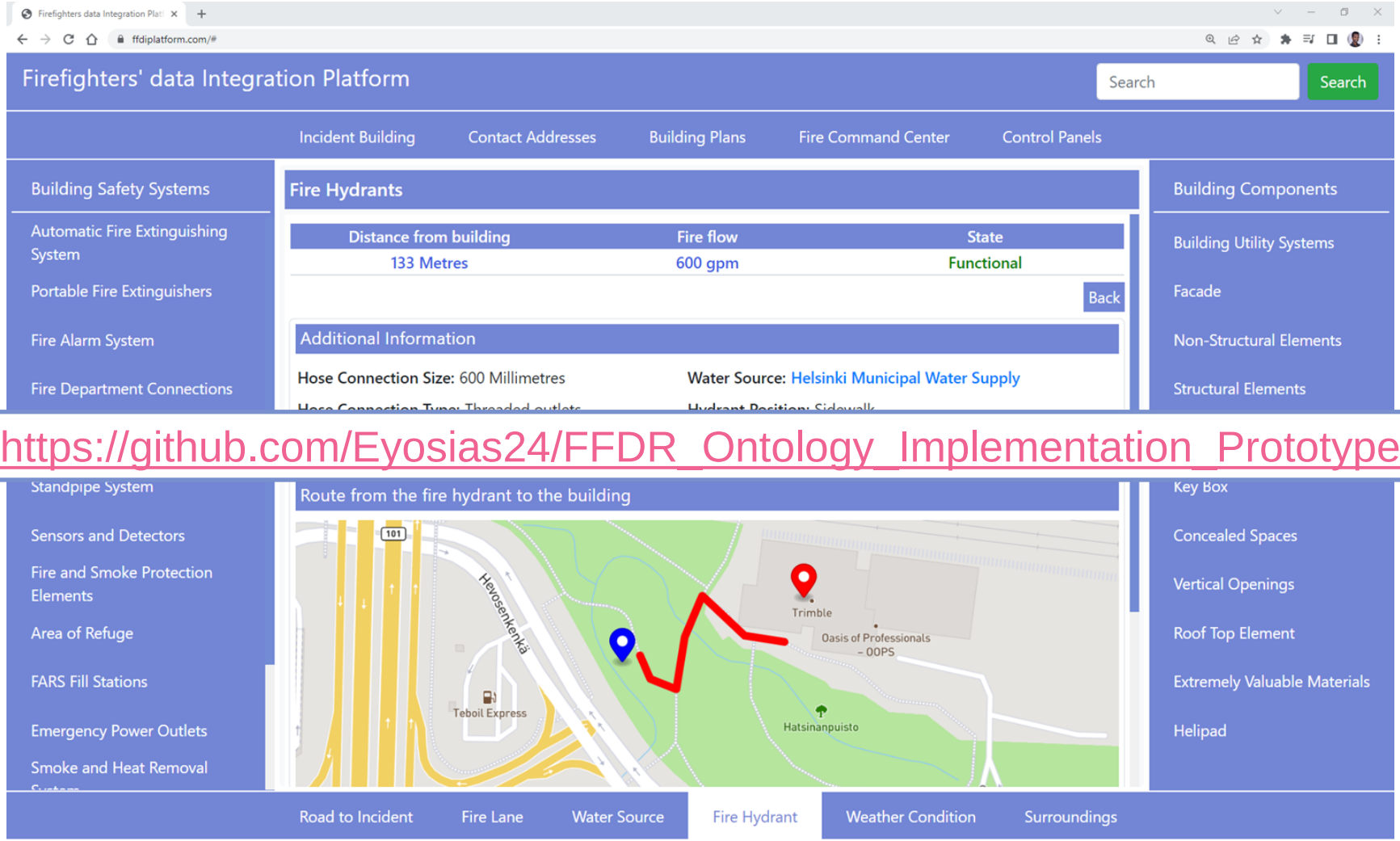
- Confirms whether an ontology corresponds to the concepts it was modelled to represent
  - Workshop with firefighters
  - Prototype

Ontology Verification

- The evaluation of the correctness and consistency of the new ontology.
- Reasoning on the ontology with **Pellet** and **HermiT** identified a few logical inconsistencies.
- **Ontology pitfall scanner!** or **OOPS!** is used to identify pitfalls in the ontology.
- Verification processes **repeated** every time the ontology is modified.

Ontology Validation: Prototype

- A **prototype web application** that visualises relevant information based on the ontology is developed.
- Developed using the **Django framework**
- **Owlready2** is used in the python script to parse the ontology from OWL format in Python.
- A thirteen-floor office building in Espoo, Finland, is selected as a case study

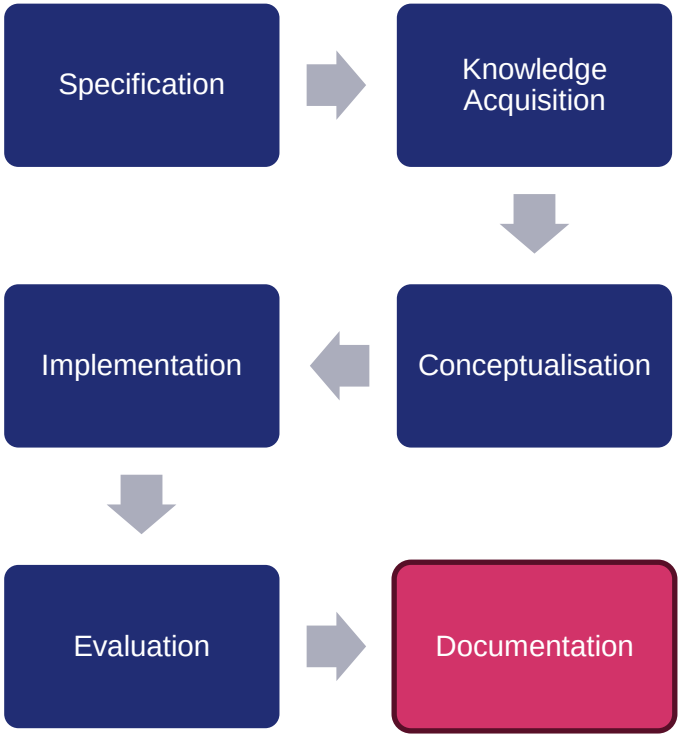


https://github.com/Eyosias24/FFDR_Ontology_Implementation_Prototype

Ontology Validation: Firefighter Interview

- **Interviews** with firefighters to assess the ontology.
- Interview identified some concepts missing in the ontology.
- Modifications are made to the ontology to address the issue.

Ontology Development



Documentation

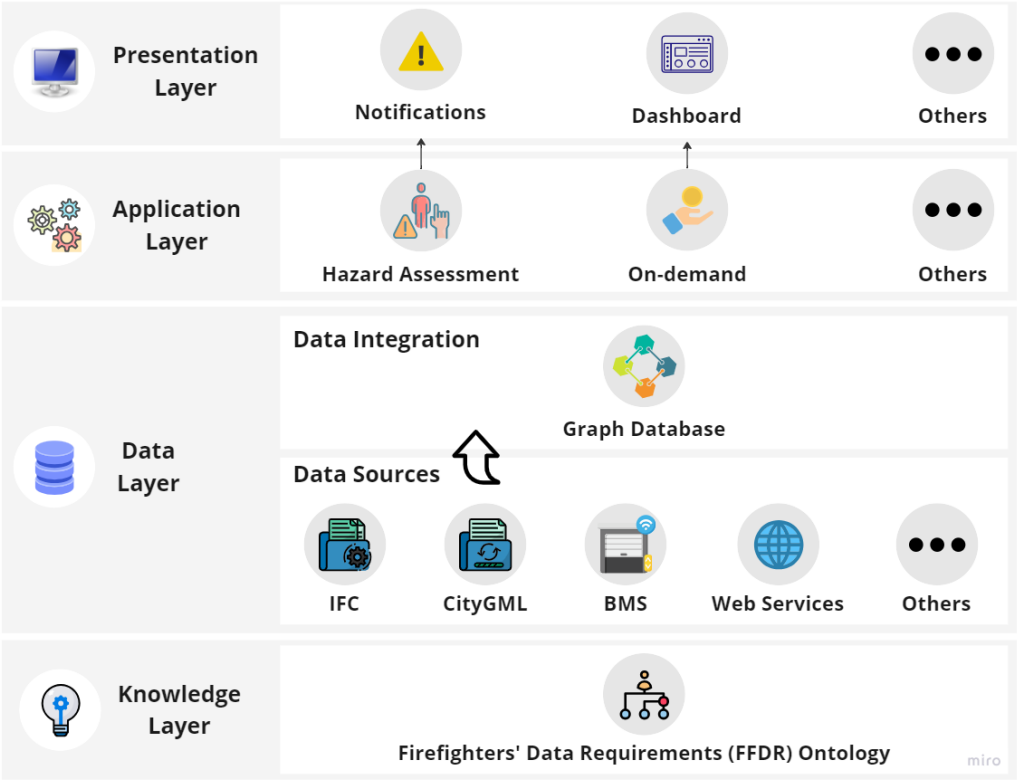
- Ontology specification document published online.
  - *Live OWL Documentation Environment (LODE)* (Peroni, Shotton, and Vitali 2012)
  - *Wizard for documenting ontologies (WIDOCO)* (Garijo 2022)

IRI: https://purl.org/ffdr-ontology

Benefits of the Research

- The ontology provides a **shared**, **structured**, and **deeper** understanding of the fire emergency domain
- Support to **standardization** efforts in the emergency management domain
- Facilitate effective **communication** and information management during emergency response operations
- Enhances **interoperability** among information systems and technologies that can be used throughout the emergency management
- Support **development** of systems that gather and provide comprehensive information to firefighters

Data Integration Framework



Data Integration Framework

1. An **automated** assessment for critical data

Year Of Construction	No Of Stories	Construction Type	Occupancy Type	Building Height	Fire Location
2021	11	"Steel"	"Office buildings"	"39.5"	"Floor_2"

Building Model

City Model

BMS

Data Integration Framework

2. **On-demand** access to the unified data

- Fire hydrants that are found near the affected building

Location (Coordinates)	Distance	Type	Diameter
24.819843, 60.217317	300	underground	600
24.82183, 60.216087	300	pillar	300
24.82398, 60.216246	400	underground	-
24.820965, 60.215392	400	underground	-
24.823942, 60.215375	500	underground	-
24.8261, 60.2152	600	underground	300

Additional Benefits of the Research

- The ontology extends its benefits to other stakeholders responsible for the safety of building occupants
- Offers imperative knowledge that is required for a better understanding of building safety
- Building designers can devise designs that ensure the safety of first responders
- Building managers and regulatory bodies can conduct conformity checks regarding the fire safety of buildings based on the knowledge in the ontology.
  - **Automated rule-checking** systems based on the ontology

Other Activities in the Research

- Comparative study of relational and graph-based data persistent systems
- We experimented with four datasets
  - Two building datasets - large and small
  - Two city datasets - large (Tokyo) and small (Espoo)
- Compared Graph DB and Relational DB based on:
  - Database design and maintenance
  - Query performance

References

Altowaijri, Abdullah H. et al. 2021. "A Privacy-Preserving Iot-Based Fire Detector." *IEEE Access* 9: 51393–402. https://click.endnote.com/viewer?doi=10.1109%2Faccess.2021.3069588&token=WzMxMjI5NzYsIjEwLjExMDkvYWNjZXNzLjIwMjEuMzA2OTU4OCJd.JZFmqHKBZWA6KnbrL8F5UE_c7R8 (February 24, 2023).

Balaji, Bharathan et al. 2016. "Brick: Towards a Unified Metadata Schema For Buildings." In *Proceedings of the 3rd ACM International Conference on Systems for Energy-Efficient Built Environments*, New York, NY, USA: ACM, 41–50. https://dl.acm.org/doi/10.1145/2993422.2993577.

Balding, Dave. 2020. "Embracing Technology - Fire Fighting in Canada." https://www.firefightingincanada.com/embracing-technology/ (August 2, 2021).

Bitencourt, Kattiuscia, Frederico Araújo Durão, Manoel Mendonça, and Lassion Laique Bomfim de Souza Santana. 2018. "An Ontological Model for Fire Emergency Situations." In *IEICE Transactions on Information and Systems*, Institute of Electronics, Information and Communication, Engineers, IEICE, 108–15.

Burel, Grégoire, Lara S.G. Piccolo, Kenny Meesters, and Harith Alani. 2017. "DoRES-A Three-Tier Ontology for Modelling Crises in the Digital Age." In *Proceedings of the International ISCRAM Conference*, , 834–45.

Ehrlinger, Lisa;, and Wolfram Wöß. 2016. "Towards a Definition of Knowledge Graphs." In *Joint Proceedings of the Posters and Demos Track of 12th International Conference on Semantic Systems - SEMANTiCS2016 and 1st International Workshop on Semantic Change & Evolving Semantics (SuCCESS16)*, Leipzig. https://www.researchgate.net/publication/323316736_Towards_a_Definition_of_Knowledge_Graphs (February 22, 2023).

Fahy, R., J. Petrolli, and J. Molis. 2019. NFPA Research Report *NFPA: Firefighter Fatalities in the US-2019*. https://www.nfpa.org/News-and-Research/Data-research-and-tools/Emergency-Responders/Firefighter-fatalities-in-the-United-States.

Fan, Zhengjie, and Sisi Zlatanova. 2011. "Exploring Ontologies for Semantic Interoperability of Data in Emergency Response." *Applied Geomatics* 3(2): 109–22. http://link.springer.com/10.1007/s12518-011-0048-y (August 10, 2021).

Fernandez, M., A. Gómez-Pérez, and Natalia Juristo. 1997. "Methontology: From Ontological Art towards Ontological Engineering." In *Proceedings of the AAAI97 Spring Symposium Series on Ontological Engineering*, Facultad de Informática (UPM), 33–40. http://speech.inesc.pt/~joana/prc/artigos/06c METHONTOLOGY from Ontological Art towards Ontological Engineering - Fernandez, Perez, Juristo - AAAI - 1997.pdf (August 16, 2021).

References

Gang Liu et al. 2011. "Towards Building Ontology for Community-Based Fire Management." In *Proceedings 2011 International Conference on Transportation, Mechanical, and Electrical Engineering (TMEE)*, IEEE, 1366–69. http://ieeexplore.ieee.org/document/6199460/.

Garijo, Daniel. 2022. "WIDOCO: A Wizard for Documenting Ontologies." https://zenodo.org/record/6470043 (July 20, 2022).

Gaur, Manas, Saeedeh Shekarpour, Amelie Gyrard, and Amit Sheth. 2019. "Empathi: An Ontology for Emergency Managing and Planning About Hazard Crisis." In *2019 IEEE 13th International Conference on Semantic Computing (ICSC)*, IEEE, 396–403. https://ieeexplore.ieee.org/document/8665539/.

Ghadi, Yazeed Yasin, M. G. Rasul, and M. M.K. Khan. 2016. "Design and Development of Advanced Fuzzy Logic Controllers in Smart Buildings for Institutional Buildings in Subtropical Queensland." *Renewable and Sustainable Energy Reviews* 54: 738–44. http://dx.doi.org/10.1016/j.rser.2015.10.105.

Ghodrat, Maryam, Farshad Shakeriaski, David James Nelson, and Albert Simeoni. 2021. "Existing Improvements in Simulation of Fire–Wind Interaction and Its Effects on Structures." *Fire* 4(27). https://www.mdpi.com/2571-6255/4/2/27.

Glimm, Birte et al. 2014. "HermiT: An OWL 2 Reasoner." *Journal of Automated Reasoning* 53(3): 245–69. https://link.springer.com/article/10.1007/s10817-014-9305-1 (November 10, 2022).

Gómez-Pérez, Asunción, Mariano Fernández, and A de Vicente. 1996. "Towards a Method to Conceptualize Domain Ontologies." In *Ontological Engineering 12th European Conference on Artificial Intelligence (ECAI'96)*, , 41–51.

Hartmann, Timo, and Amy Trappey. 2020. "Advanced Engineering Informatics - Philosophical and Methodological Foundations with Examples from Civil and Construction Engineering." *Developments in the Built Environment* 4: 100020.

Heron, Dave et al. 2003. New Zealand Fire Service Commission Research Report Number 44 *Modelling Fire-Spread In and Around Urban Centres*.

International Code Council (ICC). 2018a. *2018 International Building Code*. International Code Council, Inc.

———. 2018b. *2018 International Fire Code*. International Code Council, Inc.

Isikdag, Umit, Jason Underwood, and Ghassan Aouad. 2008. "An Investigation into the Applicability of Building Information Models in Geospatial Environment in Support of Site Selection and Fire Response Management Processes." *Advanced Engineering Informatics* 22(4): 504–19. http://dx.doi.org/10.1016/j.aei.2008.06.001.

References

Jones, Walter W et al. 2005. National Institute of Standards and Technology *Workshop to Define Information Needed by Emergency Responders during Building Emergencies*. Gaithersburg, MD. http://fire.nist.gov/bfrlpubs/fire05/art017.html.

Khalid, Qasim. 2021. "SBEO: Smart Building Evacuation Ontology. Version: 0.2." https://qasimkhalid.github.io/SBEO/ (August 13, 2021).

Laakso, Mikael, and Arto Kiviniemi. 2012. "The IFC Standard - A Review of History, Development, and Standardization." *Journal of Information Technology in Construction (ITcon)* 17: 134–61.

Lamy, Jean-Baptiste. 2017. "Owlready: Ontology-Oriented Programming in Python with Automatic Classification and High Level Constructs for Biomedical Ontologies." *Artificial Intelligence in Medicine* 80: 11–28. http://www.lesfleursdunormal.fr/static/_downloads/article_owlready_aim_2017.pdf.

Li, Nan et al. 2014. "Situational Awareness for Supporting Building Fire Emergency Response: Information Needs, Information Sources, and Implementation Requirements." *Fire Safety Journal* 63: 17–28. http://dx.doi.org/10.1016/j.firesaf.2013.11.010.

Malizia, A. et al. 2010. "SEMA4A: An Ontology for Emergency Notification Systems Accessibility." *Expert Systems with Applications* 37(4): 3380–91. https://linkinghub.elsevier.com/retrieve/pii/S0957417409008768 (August 11, 2021).

McGuinness, Deborah L, and Frank van Harmelen. 2004. "OWL Web Ontology Language Overview" eds. Deborah L McGuinness and Frank Van Harmelen. *W3C recommendation* 10(February). http://www.w3.org/TR/owl-features/.

Musen, Mark A. 2015. "The Protégé Project: A Look Back and a Look Forward." *AI Matters* 1(4): 4–12. https://dl.acm.org/doi/10.1145/2757001.2757003.

National Fire Protection Association (NFPA). 2020. *NFPA 1620: Standard for Pre-Incident Planning*. https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=1620.

———. 2021. *NFPA Glossary of Terms*.

National Wildfire Coordinating Group (U.S.). 1994. *Fire Effects Guide*. Washington, D.C.: National Wildlife Coordinating Group. file://catalog.hathitrust.org/Record/002916608.

Neto, Joaquim, António Jorge Do Nascimento Morais, Ramiro Gonçalves, and António Coelho. 2021. "An Ontology for Fire Building Evacuation." In *ICICT 2021 - 6th International Congress on Information & Communication Technology*,.

References

Noy, Natalya F., and Deborah L. McGuinness. 2001. Stanford Knowledge Systems Laboratory *Ontology Development 101: A Guide to Creating Your First Ontology*.

Nuo, Noel, Wi Tay, Naoyuki K Ubota, and János Botzheim. 2016. "Building Ontology for Fire Emergency Planning and Support." *E-Journal of Advanced Maintenance* 8(2): 13–22.

Occupational Safety and Health Administration (OSHA). 2015. *Fire Service Features of Buildings and Fire Protection Systems*.

Onorati, T., A. Malizia, P. Diaz, and I. Aedo. 2014. "Modeling an Ontology on Accessible Evacuation Routes for Emergencies." *Expert Systems with Applications* 41(16): 7124–34. https://linkinghub.elsevier.com/retrieve/pii/S0957417414003194 (January 31, 2021).

Open Geospatial Consortium. 2012. OGC Document No. 12-019 *OpenGIS City Geography Markup Language (CityGML) Encoding Standard, Version 2.0.0*. eds. Gerhard Gröger, Thomas H. Kolbe, Claus Nagel, and Karl-Heinz Häfele. https://portal.opengeospatial.org/files/?artifact_id=47842.

Pauwels, Pieter, and Walter Terkaj. 2016. "EXPRESS to OWL for Construction Industry: Towards a Recommendable and Usable IfcOWL Ontology." *Automation in Construction* 63: 100–133. https://technical.buildingsmart.org/standards/ifc/ifc-formats/ifcowl/ (November 10, 2022).

Peroni, Silvio, David Shotton, and Fabio Vitali. 2012. "The Live OWL Documentation Environment: A Tool for the Automatic Generation of Ontology Documentation." In *Proceedings of the 18th International Conference on Knowledge Engineering and Knowledge Management*, http://speroni.web.cs.unibo.it/publications/peroni-2012-live-documentation-environment.pdf (July 20, 2022).

Poveda-Villalón, María, Asunción Gómez-Pérez, and Mari Carmen Suárez-Figueroa. 2014. "OOPS! (OntOlogy Pitfall Scanner!)." *International Journal on Semantic Web and Information Systems* 10(2): 7–34. http://services.igi-global.com/resolvedoi/resolve.aspx?doi=10.4018/ijswis.2014040102.

Rasmussen, Mads Holten, Maxime Lefrançois, Georg Ferdinand Schneider, and Pieter Pauwels. 2020. "BOT: The Building Topology Ontology of the W3C Linked Building Data Group" ed. Krzysztof Janowicz. *Semantic Web* 12(1): 143–61. https://www.medra.org/servlet/aliasResolver?alias=iospress&doi=10.3233/SW-200385.

Rauch, Nadia, and Mark Fox. 2017. *A Fire and Emergency Ontology for City Indicators*.

Saad, Elie, Koen V. Hindriks, and Mark A. Neerincx. 2018. "Ontology Design for Task Allocation and Management in Urban Search and Rescue Missions." In *Proceedings of the 10th International Conference on Agents and Artificial Intelligence*, SCITEPRESS - Science and Technology Publications, 622–29. http://www.scitepress.org/DigitalLibrary/Link.aspx?doi=10.5220/0006661106220629 (August 10, 2021).

References

Santarpia, Luciano et al. 2019. "Fire Temperature Based on the Time and Resistance of Buildings—Predicting the Adoption of Fire Safety Measures." *Fire* 2(2): 19. https://www.mdpi.com/2571-6255/2/2/19.

Sassani, Bahman A. et al. 2020. "FireNot – An IoT Based Fire Alerting System: Design and Implementation." *Journal of Ambient Intelligence and Smart Environments* 12(6): 475–89. https://www.medra.org/servlet/aliasResolver?alias=iospress&doi=10.3233/AIS-200579 (February 24, 2023).

Sirin, Evren et al. 2007. "Pellet: A Practical OWL-DL Reasoner." *Journal of Web Semantics* 5(2): 51–53.

Uschold, Mike, and Michael Gruninger. 1996. "Ontologies: Principles, Methods and Applications." *The Knowledge Engineering Review* 11(2): 93–136. https://www.cambridge.org/core/journals/knowledge-engineering-review/article/abs/ontologies-principles-methods-and-applications/2443E0A8E5D81A144D8C611EF20043E6 (February 22, 2023).

Vilgertshofer, S. et al. 2017. "Linking BIM and GIS Models in Infrastructure by Example of IFC and CityGML." In *ASCE International Workshop on Computing in Civil Engineering 2017*, American Society of Civil Engineers (ASCE), 133–40.

Vinasco-Alvarez, D., J. Samuel, S. Servigne, and G. Gesquière. 2020. LIRIS UMR 5205 *From CityGML to OWL*.

Wehbe, Rania, and Isam Shahrour. 2021. "A BIM-Based Smart System for Fire Evacuation." *Future Internet* 13(9): 221. https://www.mdpi.com/1999-5903/13/9/221.

Xu, Wei, and Sisi Zlatanova. 2007. "Ontologies for Disaster Management Response." In *Geomatics Solutions for Disaster Management*, eds. Jonathan; Li, Sisi; Zlatanova, and Andrea G. Fabbri. Berlin, Heidelberg: Springer Berlin Heidelberg, 185–200. http://link.springer.com/10.1007/978-3-540-72108-6_13.

Thank you!

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