Towards a Harmonized Information Exchange in the Construction Industry: An Approach Using Modular Ontology Modelling and LOIN

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Abstract

The construction industry is characterized by fragmentation due to the distinct phases, as well as the complex structure of the industry itself. The numerous processes involve diverse stakeholders each requiring seamless integration through the accurate transfer of information to maintain its integrity. Different information models both those defined by standards and industry-specific, complicate the choice of models to adopt, impacting interoperability. This research aims to develop a methodology to address this issue by unifying existing ontologies developed for different information models. The approach combines elements of the Modular Ontology Modelling methodology, and the Level of Information Need (LOIN). This methodology is currently being evaluated in collaboration with multiple companies in the Swedish AEC industry as part of an ongoing project. Results suggest using standardized machine-readable data templates, industry accepted data dictionaries and ontologies based on standards enable unambiguous exchange of information along the value chain of a construction project.

Keywords: Information models, Data templates, Modular Ontology Modelling, Level of Information Need, Construction sector, Interoperability

1 Introduction

Currently, the construction industry is known to be fragmented due to increasing specialization and division of labour (Turk 2020). The sector is characterized by a multitude of processes that occur at various stages, each involving a diverse range of stakeholders. The seamless integration of these processes necessitates the unimpeded and accurate transfer of information from one stage to the next, ensuring both the preservation of its original meaning and the maintenance of its integrity (Sacks et al. 2018).

As the exchange of information evolved from drawings on paper to computer-aided design/drawings (CAD), the industry was opened to a vast influx of software packages which could enable advanced analysis and simulations. Nevertheless, it resulted in information silos as the different software could not effectively communicate (Wang et al. 2023). This led to a juncture where information must be extracted manually and interpreted by the different actors resulting in reduced efficiency and accuracy (Wu and AbouRizk 2023). It is therefore pertinent to the advancement of the construction industry to facilitate the flow of information along the entire value chain.

Domain models (DM) establish a structure that delineates the connections between essential concepts in the construction sector, facilitating the digital exchange of data (Atkinson et al. 2008). In this context, DM refers to an information model specific to a domain. They are supported by Data templates (DT), data dictionaries, and digital workflows (Kebede et al. 2022). Standards like the ISO 19650 series, (ISO 23386 2020), ISO 23387 (2020), ISO 12006-2 (2015) and the IFC standard, (ISO 16739 2018) offer guidance on organizing, digitizing, and structuring information concerning buildings and civil engineering projects, with the goal of enhancing information management across the lifecycle of the built environment.

DMs offered so far nonetheless do not completely cover all concepts along the life cycle of a construction project. As stated by Pauwels and McGlinn (2022), "*There will never be a single unified data language, model, or schema that will accommodate all software, program languages, or user data requirements to enable seamless, efficient, and error-proof data exchange*." Consequently, a paradigm shift is essential to recognize that data models need not be exhaustive to capitalize on the advantages of attaining uninterrupted data interchange. This ideology serves as the basis for the Modular Ontology Modelling (MOMo) methodology proposed by Shimizu et al. (2023). Here, the key concepts are modelled as modules in a way that facilitates the inclusion of newly developed concepts in the future.

Therefore, the aim of this research is to address the challenges of digital information exchange and interoperability in the construction sector by proposing standardized structures for the efficient and secure flow of digital product information throughout the construction process. The research questions to be answered are: -RQ1. How can the information models in use in the industry today be translated into ontologies? -RQ2. How can the information models in use today in the construction industry be harmonised?

2 Theoretical Background

The seamless exchange and management of information across different domains and project stages can be potentially achieved by several key technologies and methodologies, including data templates, levels of information need, domain models, the semantic web, etc. Interoperability ensures that diverse construction software systems can effectively communicate, enabling stakeholders to exchange data reliably and accurately. These areas have been simultaneously developed over the last decade and are discussed in the following sub-sections (Pauwels et al. 2017; Turk 2020; Schröter and Thome 2022).

2.1 Interoperability

Efforts towards achieving interoperability in the construction sector focus largely on integrating technologies like Building Information Modelling (BIM) with other systems to streamline information flow across project lifecycles. Key advancements include BIM integration with business process models and notation (BPMN) (Al-Siah and Fioravanti 2022), enhanced interoperability between BIM and Building Energy Models (BEM) and the adaptation of standardized protocols for data exchange among various BIM objects. Al-Siah and Fioravanti (2022) focused on the barriers to interoperability in the construction industry where these barriers were categorized into three main types: conceptual, technological, and organizational barriers. They went on to propose a method of BIM and BPMN integration based on cloud storing and connecting, and central database. Turk (2020) however reiterated that perfectly interoperable integrated systems will never exist after a thorough examination of interoperability in construction where the types and levels of interoperability are delineated in accordance with the New European Interoperability Framework (Commission and Services 2017). Turk (2020) ascertained that the types of interoperability are between persons, systems, and person-system with the layers of interoperability being legal, organizational, semantic, and technical interoperability, giving one category more than Al-Siah & Fioravanti (2022). In the context of this study, interoperability refers to system-system interoperability type and at the semantic layer.

2.2 Domain models

A domain model as alluded to in Section 1 is therefore a high-level abstraction and representation of entities and their relationships within a domain (Pras and Schoenwaelder 2003). Information models in the construction industry play a vital role in organizing and managing specialized knowledge which aids in effective communication and decision-making throughout different stages of construction projects (Park and Shin 2023). In the Swedish construction industry, models utilize the ISO 12006-2 standard to establish classification systems and serve as a basis for developing domain models. By adhering to these standards, domain models ensure that all project stakeholders have a common understanding of project elements, enhancing collaboration and efficiency. These models not only simplify complex construction concepts but also standardize processes, resulting in streamlined operations and reduced errors across the project lifecycle. According to (Ekholm 2005) there are two major candidates for domain models for the construction and facilities management sector, ISO 12006-2, and ISO 16739-1:2018 (IFC). In this work we have chosen to focus on ISO 12006-2 as most of the information used in the industry is organised, using ISO 12006-2. It should however be noted that harmonization of the two models into a coordinated domain framework is still considered as a way forward (Ekholm 2005).

2.3 Data dictionaries

Data dictionaries are centralised repositories of information about data such as meaning, relationships to other data, origin, usage, and format (Pauwels and McGlinn 2022). The buildingSMART Data Dictionary (bsDD), a service offered by buildingSMART International, serves as a central reference for definitions of properties and objects in the construction industry. The bsDD houses definitions from IFC, Uniclass, OmniClass, and others. The standard, ISO 23386, specifies a methodology to describe, author and maintain properties in interconnected data dictionaries. This ensures that defined properties are unambiguous and machine-readable.

2.4 Data templates

A data template is a structure with the ability to support all the information required for construction products during their lifecycle. For construction objects, ISO 23387 defines concepts and principles of for how DTs are structured. These templates provide a structured format for capturing and communicating essential information in a uniform way across different software systems and project phases, enhancing interoperability and consistency. It allows for a smooth integration of product data into BIM systems, optimizing the design, construction, and operational efficiencies (Mêda et al. 2020).

2.5 Level of information need (LOIN)

As part of increasing efficiency is the generation of information for a specific purpose. Information is relevant when it has a purpose. Level of information need helps put construction information into context. An exchange of information that follows the LOIN guidelines has four prerequisites: purpose, milestone, actor, and object. The concepts and principles are defined in the, EN 17412-1. In Sweden, Nationella Riktlinjer (Riktlinjer 2023)has implemented the LOIN standard with a modification by adding a fifth prerequisite on the granularity of the delivered data. This shows at the level of detail be it functional, design, component, or article at which information is delivered. The prerequisites are however defined by respective standards, ISO 22263 for project milestones, SS32202:2011 for actors, Swedish national guidelines (Nationella Riktlinjer) for purposes, and bsDD and CoClass services provide definitions for objects.

2.6 Semantic web

Semantic Web in the context of the construction industry involves applying structured data and ontologies to enhance interoperability, data sharing, and decision-making processes in building projects. This concept leverages technologies and standards such as RDF (Resource Description Framework), OWL (Web Ontology Language), and SPARQL (a query language) to create a web of data that can be processed by machines.

Pauwels and McGlinn (2022) emphasize the significance of Semantic Web technologies in modelling building information to facilitate advanced semantic queries and automated reasoning. This approach allows for richer descriptions and more precise retrieval of data, which are critical in the complex ecosystem of construction projects. Leveraging these advantages of Semantic Web ontologies contribute to improving information exchange processes in the management of existing buildings, thereby supporting maintenance and operations through enhanced data access and interpretation (Sadeghineko and Kumar 2022).

2.7 Modular Ontology Modelling (MOMo)

The MOMo method is a structured approach for developing ontologies that emphasizes modularity and the use of design patterns. It involves creating small, manageable ontology modules based on reusable templates known as Ontology Design Patterns (ODPs). The MOMo methodology was proposed by (Shimizu et al. 2023). This method has been implemented in earlier research (Shimizu et al. 2023; Kebede et al. 2024). The methodology starts with defining a use case, gathering competency questions to guide the ontology's capabilities, identifying key notions for modules, and integrating these modules using a tool called CoModIDE. This tool supports graphical modelling and easy pattern integration. This method is employed because apart from its modular approach, it promotes collaborative, iterative development with stakeholders and emphasizes practical usability and documentation, making it suitable for complex and evolving domains.

3 Methodology

This research employs a design research method in accordance with the Modular Ontology Modelling (MOMo) methodology. Within this method, a case study and focus groups are employed. The case study seeks to follow through the lifecycle of a building project within a range of selected project milestones to observe the implementation of the information exchange at the different phases. The focus groups, composed of parties from academia and industry, provide input in the development of ontology. A search is first made to obtain ontologies that can be integrated. As the implementation of this method relies on standards and guidelines for uniformity, an analysis of standards is carried out in connection to the case study.

3.1 Document analysis

In this research, selected standards relevant to the use case undergo analysis based on their relevance to the use case to ensure their effective application in the field of construction and building information modelling (BIM). The analysis focuses on scope of the standards and their significance to the use case.

3.2 MOMo methodology

The MOMo method is a ten-step program involving domain experts. As this is an ongoing project, the first three steps outlined in Table 1 will be followed as a foundation to develop an ontology for the case study. The term entire team refers to all participants of the focus group discussions. Domain experts are pooled from the Department of Construction Engineering and Lighting Science at the School of Engineering, Jönköping University, and industry partners from the Datamallar project. This is further described in section 3.2.1. Except otherwise specified, output document formats may be in LaTeX, Word, or HTML.

Table 1. MOMo method steps with corresponding actors and expected output. Adapted from (Shimizu et al. 2023)

Step	Responsible	Output
Describe use cases & data sources	Entire team	Use case descriptions
Gather competency questions	Entire team	List of CQs
Identify key notions	Entire team	List of key notions
Identify existing ODPs	Ontology engineers	Selected ODP(s) for each key notion

Create module diagrams	Entire team	Diagrammatic representation of the solution module
Document modules & axioms	Ontology engineers & domain experts	Module documentation with embedded schema diagrams, axiomatization, etc.
Create ontology diagram	Ontology engineers	Diagrammatic representation of the whole composed ontology
Add spanning axioms	Ontology engineers	Documentation of the entire ontology with embedded schema diagrams, axiomatization, etc.
Review naming & axioms	Ontology engineers	Updated module and ontology documentation
Create OWL file & axioms	Ontology engineers	An OWL file for publication and use

3.2.1 Focus group

In executing the steps in Table 1 focus group discussions are held with Datamallar's industry partners and domain experts. Datamallar is the short name given to the Swedish research project titled *Digitala datablad baserat på datamallar* (*Digital data sheets based on data templates*).(Erlandsson 2023). Focus group discussions are conducted to gather insights into the information exchange processes, existing information models, and challenges faced by stakeholders in the industry. Domain analysis is performed to identify key notions, relationships, and terminologies relevant to the construction domain, laying the groundwork for development of a domain model. The domain model is built on the key notions which are aligned with existing ontologies. These sessions aim to gather qualitative insights into the practical aspects of information requirements at various milestones. The discussions are structured around the MOMo methodology, ensuring a systematic and comprehensive exploration of the subject matter. The results are therefore presented and analysed within the MOMo method.

3.3 Case study and LOIN approach

The project's case study consists of a room defined by four walls, a slab, and a ceiling. Light fixtures are installed on the ceiling. The case study has been designed in collaboration with the focus group. The process begins with a detailed analysis of the client's room functional program, by the architect. A light designer then conducts simulations to determine the optimal lighting fixtures. These simulations are based on various parameters, including spatial dimensions, light intensity requirements, and aesthetic considerations. The products chosen by the lighting design can also be seen as a basis for requirements. This is done by defining certain properties as critical or key properties. The contractor uses these requirements (key properties) to propose a final product selection. The goal is to align the lighting design with the client's needs and the architectural vision.

The focus of the case study is to define a workflow that enables machine-readable exchange of construction information. To guide the exchange of data in the case study, LOIN is used to prepare exchange information requirements (EIR).

4 Results

The standards have been analysed and classified based on their relevance to the case. The document analysis results, as shown in Table 2, offer an overview of international standards and those adapted locally, all pertinent to information management in construction projects. These standards collectively provide a framework for effective information management in construction projects. In this analysis, guidelines from the Swedish National Guidelines (Nationella Riktlinjer) were also considered to ensure the results are aligned with the practices of the building industry in Sweden.

4.1 MOMo methodology

As the project is ongoing, the steps have been followed through to the third step and the results are shown in forthcoming subsections.

4.1.1 Use case and competency questions

The MOMo method began with a use case[1] which was defined following the principles of the bsDD use case management (UCM). The competency questions border on the space lighting requirements and light fixture properties and are listed as follows:
CQ1. Which room needs could be met by light fixture A?
CQ2. What are the requirements for room X?
CQ3. Which light fixtures did the lighting designer choose for room X?
CQ4. Which light fixtures were installed in room X?
CQ5. Can light fixture B replace light fixture A?

Table 2. Document analysis results

Standard/Guidelines	Scope	Relevance
ISO 29481-1	Defines data exchange requirements using IDM	Process modelling
ISO 29481-2	Details an interaction framework to support IDM. How different systems can communicate	Structured interaction exchange between actors in XML
ISO 12006-2	Structuring data for consistency across different systems	Uniform understanding of objects and properties
ISO 12006-3	Defines a framework for object-oriented information	Creation of digital representations of objects and properties
ISO 23387	Guide on creating and managing data templates.	Development of data templates for information delivery at all stages
ISO 19650 series	Guidelines and best practices for managing information over the whole life cycle of a construction project.	Standardization of information management over the project life cycle
SS EN 17412-1	Specifies requirements for the level of information needed for BIM assets.	Definition of specific information requirements at each stage.
ISO/TS 7127:2023	Standardized properties for lighting systems	Provision of standardized set of properties for light and lighting systems
Nationella Riktlinjer	Guidelines on the handling of digital information for the built environment	Compliance in the Swedish context
ISO 22263:2008	Management of project information, ensuring consistency and accessibility of information among all project stakeholders at different stages	Definition of milestones for LOIN implementation
ISO 16739-1:2018	Defines IFC for data sharing in the construction and facility management industries	Definition of objects and properties

4.1.2 Key notions

In developing the use case with the focus group, a process diagram outlining the processes and information exchanges was created. The key notions, obtained from the objects and process

[1] https://github.com/sosabaa/Datamallar/blob/main/Use%20Case%20Documentation.md

described in the use case are aligned with the ISO 12006-2, Real Estate Core (REC) ontology, and CoClass. These key notions resulted in the development of a domain model (Figure 1). The model consists of four modules, process, constructional, spatial and functional contexts which are defined by colour of the rectangular boxes. The concept of LOIN from ISO 17412-1 is included to capture information delivery at different stages based on practical industry applications from Nationella Riktlinjer and CoClass. Table 3 shows key notions and their relation to the use case. This model serves as the basis upon which ontologies are integrated.

4.1.3 Existing ontologies for alignment

Through interactions with industry partners, existing ontologies that can be possibly aligned with the ontology in development were explored. These are summarized in Table 4.

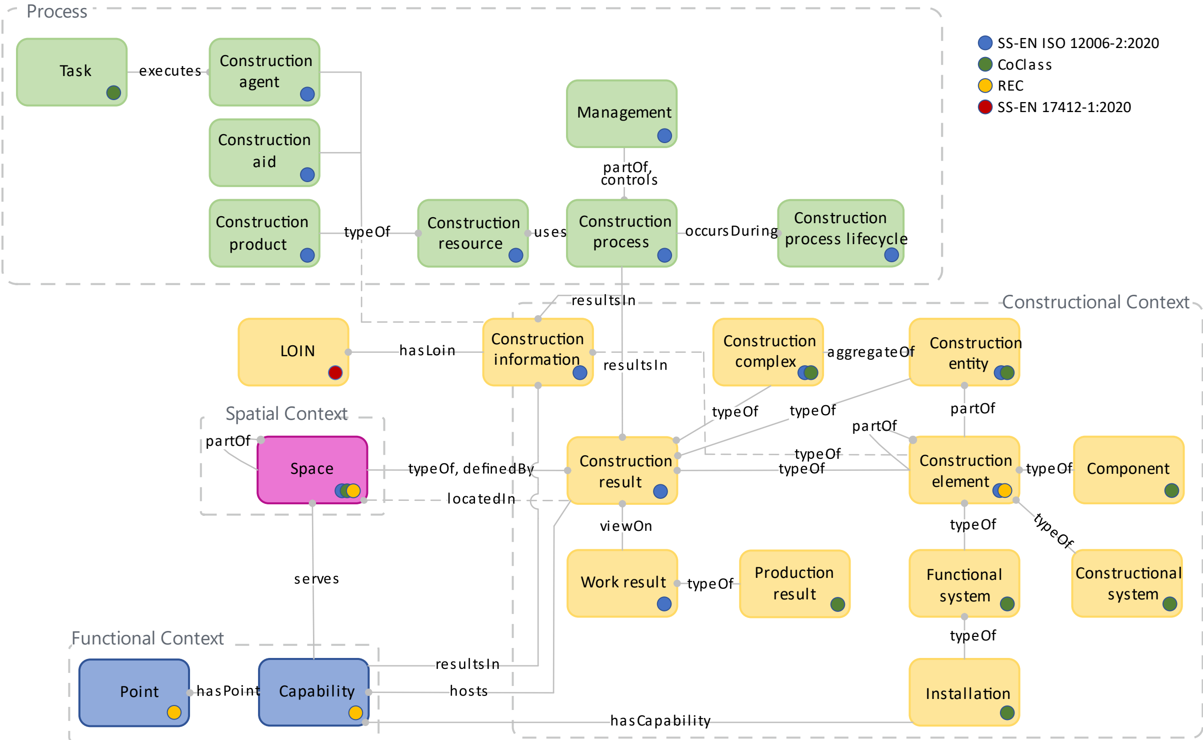

Figure 1. Domain model (Adapted from Workgroup 4, Datamallar)

Table 3. Key notions and relation to the use case

Key notion	Use case elements
Construction agent	Actors
Construction information	EIRs, IDMs, Product databases
Construction element	Light fixture
Space	Office space
LOIN	Includes all elements necessary to define level of information need eg. milestone, purpose, level of detail, etc.

Table 4. Existing relevant ontologies

Ontology	Status
Real estate core (REC)	Published
LOIN ontology (Liu et al. 2023)	Research
ISO 12006-2	Under development
CoClass ontology	Under development

4.2 Case study and LOIN approach

The use case developed together with the industry was broken down into phases using project stages defined by ISO 22263. The interactions between the different actors were transformed into EIRs following ISO 29481-1. The exchange requirements were created in an excel spreadsheet and thereafter IDS XML files were produced in a semi-automated way. This process was carried out simultaneously in Cobuilder Link, a platform which provides a way to structure information in data templates. However, the limitation of this process is evident when attempting to provide machine-readable LOIN specifications using IDS. Objects and properties were identified by their URIs or GUID. Data dictionaries from which the properties are picked are referenced in the IDS. In this EIR, the issuer has the option of specifying if properties are key properties (i.e. an essential attribute of the information being exchanged. The level of detail for this designation is established by Nationella Riktlinjer and the actors as defined in ISO 17412-1. The IDS schema was modified to allow URI attribute on entity. For example, the attribute, 'ifcVersion', was replaced with 'dictionary' to make specifications inclusive of other data definitions. An overview of modifications to the IDS schema is presented in Table 5.

Table 5. Overview of additions and modifications to existing IDS schema

Modification	Reason
Introduction of 'detail'	To capture level of detail according to Nationella Riktlinjer
Introduction of 'actor'	To conform with ISO 17412-1
Introduction of URI attribute for entity element	Unique identification of objects to facilitate unambiguity
Introduction of 'keyProperty' as property attribute	To enable issuers of IDMs to define if a requested property is a key property or otherwise
Modified 'ifcVersion' to 'dictionary'	To make specification inclusive by allowing other standards to be defined
Introduction of ISO/TS_7127:2023 as a dictionary (ifcVersion)	To include standardized definitions for lighting properties

5 Discussion

This study sought to answer two questions in the construction industry namely: -RQ1. How can the information models in use in the industry today be translated into ontologies? -RQ2. How can the information models in use today in the construction industry be harmonised? The results of the methods employed in relation to the questions are discussed in this section.

The application of the MOMo methodology, as outlined in the results section, demonstrates a systematic approach to developing and implementing ontologies that cater to the specific needs of construction projects. The process began with defining use cases and gathering competency questions, which were essential in identifying the key notions that would form the basis of the ontology modules. This approach is particularly significant in addressing the fragmented nature of the industry, as it ensures that the developed ontology is both relevant and adaptable to evolving project requirements and technological advancements. The key notions shown overlap different ontologies which will be reused in the final ontology. Integrating the ontologies in such a manner decreases the possibility of creating overlapping ontologies along with its drawbacks (Ochieng and Kyanda 2018). The case study and LOIN approach highlighted in the results provided practical insights into the methodology's application, showing promising outcomes in enhancing data exchange and interoperability through an overarching domain model.

The LOIN guidelines played a crucial role in this research by establishing clear criteria for the level of detail required at each stage of information exchange. The implementation of LOIN helped in setting precise specifications for the information delivery, which is critical in avoiding information overload and ensuring that each stakeholder receives only the most relevant and necessary data (Egbu and Botterill 2003). By defining the prerequisites such as purpose, milestone, actor, and object—and including an additional attribute of granularity—the LOIN approach tailored the information flow to the specific needs of the project, enhancing both efficiency and effectiveness. Having this level of flexibility in specifying EIRs in IDS format can allow the inclusion of many standards presently and in the future.

While the case study and LOIN approach have shown promising results, they also bring to light challenges experienced in practice. One major issue is the adaptation of these methodologies to accommodate diverse project requirements of project stakeholders. This came up frequently in the focus group discussion where stakeholders expressed the inability of IFC to cater for all their needs in terms of standardized properties. The necessity to modify the IDS schema to include non-standard attributes and to broaden the scope of recognized standards points to a need for standardized machine-readable format for LOIN specifications.

6 Future research

Given the outcomes and the identified challenges, future research should focus on refining these methodologies to increase their adaptability and scalability. Further studies could explore the integration of additional digital tools and standards to enhance the LOIN approach, potentially automating more aspects of the information delivery process and elevating the LOIN specifications to RDF levels to carry out automated model checks. Additionally, expanding the case study to include more diverse project types and more complex construction environments could provide deeper insights into the universal applicability of the MOMo and LOIN methodologies.

Together, these methodologies foster a more structured, consistent, and effective digital ecosystem within the construction industry. They not only address the fragmentation and inefficiencies traditionally associated with construction projects but also pave the way for leveraging advanced technologies such as artificial intelligence and machine learning in the future.

7 Conclusion

The integration of the Modular Ontology Modelling (MOMo) methodology and the Level of Information Need (LOIN) approach in the construction industry offers a significant step forward in addressing the ongoing challenges of interoperability, information management, and communication among diverse project stakeholders. This study has demonstrated the practical applicability and benefits of these methodologies, providing a robust framework for improving digital information flow throughout construction projects. However, further evaluation is still needed.

The MOMo methodology, with its emphasis on modularity and adaptability, offers a solution that accommodates the evolving nature of construction projects and the diverse needs of stakeholders. It facilitates the development of tailored ontologies that enhance the semantic richness and usability of construction data. The LOIN approach complements this by ensuring that the information exchanged across various phases of construction is precisely aligned with the specific needs and contexts of the project, thereby optimizing the relevance and efficiency of data usage. The data and findings are however limited to the Swedish construction industry and more standards and industries will have to be considered in order to widen the scope of this research.

8 Data availability

The developed ontology, documentation and data generated for evaluation in this paper are provided in https://github.com/sosabaa/Datamallar/tree/main.

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