# ONTOLOGIES AND KNOWLEDGE GRAPHS IN UNIVERSITY PUBLIC MANAGEMENT: IFES-GENIUS-EXT AS A TOOL FOR TRANSPARENCY AND INTELLIGENT AUDITING

# ONTOLOGIAS E GRAFOS DE CONHECIMENTO NA GESTÃO PÚBLICA UNIVERSITÁRIA: A IFES-GENIUS-EXT COMO FERRAMENTA PARA TRANSPARÊNCIA E AUDITORIA INTELIGENTE

# ONTOLOGÍAS Y GRAFOS DE CONOCIMIENTO EN LA GESTIÓN PÚBLICA UNIVERSITARIA: IFES-GENIUS-EXT COMO HERRAMIENTA PARA LA TRANSPARENCIA Y LA AUDITORÍA INTELIGENTE

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## ABSTRACT

The article proposes an innovative approach to university public management based on ontologies and knowledge graphs, using the IFES-GENIUS-EXT ontology as a case study. The research is grounded in the METHONTOLOGY and NeOn methodologies, integrating theoretical foundations of Knowledge Engineering and Knowledge Management with practical applications in Federal Higher Education Institutions (IFES). The proposed model aims to improve the representation, interoperability, and reasoning over institutional data related to planning, performance indicators, and financial investments. Through a formal structure expressed in OWL and RDF, the ontology promotes semantic integration among administrative systems, enabling intelligent auditing and greater public transparency. The study also discusses the challenges of semantic governance in university environments, proposing mechanisms for collaborative maintenance and the use of national standards (VCGE, DCAT-AP.br, e-SIC). It is concluded that IFES-GENIUS-EXT represents a significant step toward consolidating the use of Knowledge Graphs in university management, offering support for accountability and intelligent auditing in Brazilian public contexts.

**Keywords:** Knowledge Engineering. Ontologies. Public Management. Federal Higher Education Institutions. Knowledge Graphs.

## RESUMO

O artigo propõe uma abordagem inovadora para a gestão pública universitária baseada em ontologias e grafos de conhecimento, tendo como estudo de caso a ontologia IFES-GENIUS-EXT. A pesquisa fundamenta-se nas metodologias METHONTOLOGY e NeOn, integrando fundamentos teóricos da Engenharia e Gestão do Conhecimento com aplicações práticas em Instituições Federais de Ensino Superior (IFES). O modelo proposto visa aprimorar a representação, a interoperabilidade e o raciocínio sobre dados institucionais de planejamento, indicadores de desempenho e investimentos financeiros. Por meio de uma estrutura formal expressa em OWL e RDF, a ontologia promove integração semântica entre

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sistemas administrativos, possibilitando auditorias inteligentes e maior transparência pública. O estudo também discute os desafios da governança semântica em ambientes universitários, propondo mecanismos de manutenção colaborativa e uso de padrões nacionais (VCGE, DCAT-AP.br, e-SIC). Conclui-se que a IFES-GENIUS-EXT constitui um passo significativo para consolidar o uso de Grafos de Conhecimento na gestão universitária, oferecendo suporte à accountability e à auditoria inteligente em contextos públicos brasileiros.

**Palavras-chave:** Engenharia do Conhecimento. Ontologias. Gestão Pública. Instituições Federais de Ensino Superior. Grafos de Conhecimento.

**RESUMEN**

El artículo propone un enfoque innovador para la gestión pública universitaria basado en ontologías y grafos de conocimiento, teniendo como estudio de caso la ontología IFES-GENIUS-EXT. La investigación se fundamenta en las metodologías METHONTOLOGY y NeOn, integrando fundamentos teóricos de la Ingeniería y Gestión del Conocimiento con aplicaciones prácticas en Instituciones Federales de Educación Superior (IFES). El modelo propuesto tiene como objetivo mejorar la representación, la interoperabilidad y el razonamiento sobre datos institucionales relacionados con la planificación, los indicadores de desempeño y las inversiones financieras. Mediante una estructura formal expresada en OWL y RDF, la ontología promueve la integración semántica entre sistemas administrativos, posibilitando auditorías inteligentes y una mayor transparencia pública. El estudio también analiza los desafíos de la gobernanza semántica en entornos universitarios, proponiendo mecanismos de mantenimiento colaborativo y el uso de estándares nacionales (VCGE, DCAT-AP.br, e-SIC). Se concluye que IFES-GENIUS-EXT constituye un paso significativo para consolidar el uso de grafos de conocimiento en la gestión universitaria, ofreciendo soporte para la rendición de cuentas y la auditoría inteligente en contextos públicos brasileños.

**Palabras clave:** Ingeniería del Conocimiento. Ontologías. Gestión Pública. Instituciones Federales de Educación Superior. Grafos de Conocimiento.

## 1 INTRODUCTION

The digital transformation in the public sector has promoted a profound reconfiguration of management processes, requiring new forms of representation, integration and analysis of institutional knowledge (Nam & Pardo, 2011; Janssen et al., 2020). In federal public universities, this change is even more challenging, given the multiplicity of systems, indicators, strategic plans, and evaluation instruments that coexist in a fragmented manner (Lima et al., 2023; Silva et al., 2024). The absence of semantic standardization and intelligent interoperability mechanisms limits the transparency, governance, and auditing capacity of these institutions (Machado & Nobre, 2022).

In this context, **Ontology Engineering** constitutes a fundamental axis of Engineering and Knowledge Management, offering formal instruments to structure, share and reason about complex data in a consistent and interoperable way (Gruber, 1993; Guarino, 1998; Bittencourt et al., 2019). Ontologies allow the construction **of Knowledge** Graphs that articulate entities, relationships, and meanings, favoring the creation of systems capable of answering complex questions (*Competency Questions*) and supporting evidence-based decision-making (Hogan et al., 2021; Paulheim, 2017).

The proposal of this study is part of this scenario, with the main objective of developing and validating the **IFES-GENIUS-EXT Ontology**, an extension of **the GENIUS Ontology** (Bittencourt et al., 2019) adapted to the Brazilian context of the **Federal Institutions of Higher Education (IFES).** The model aims to structure, in a semantic way, information on **institutional planning, performance indicators, and budget allocation**, connecting them to national interoperability standards and open data, such as **VCGE, DCAT-AP.br,** and **e-SIC** (Brasil, 2019; Ministry of Economy, 2022).

The relevance of this proposal is anchored in three complementary axes. The first is **scientific**, by consolidating a specific ontological basis for the domain of public university management, expanding the reach of GENIUS Ontology and strengthening the line of research in **Graphs of Knowledge Applied to Public Management** (Ji et al., 2023; Abu-Salih & Alotaibi, 2024). The second is **technological**, by offering an interoperable semantic infrastructure, expressed in OWL and RDF, which enables automatic queries via SPARQL and validation by tools such as Protégé and SHACL (Suárez-Figueroa et al., 2012; Fernández-López et al., 1997). The third is **institutional**, by contributing to **transparency, intelligent auditing, and accountability** practices, in line with digital government guidelines and the UN Sustainable Development Goals (UN, 2021; Diamantini et al., 2025).

Based on this theoretical and methodological framework, the work proposes not only a conceptual model, but a **practical semantic infrastructure** of knowledge governance

capable of integrating multiple data sources, improving internal control and promoting the reuse of information at different levels of university management. Thus, the application of ontologies and knowledge graphs as instruments of innovation and transparency in public administration is consolidated, contributing to the construction of **intelligent and auditable universities**.

## 2 THEORETICAL FRAMEWORK

This chapter aims to establish the theoretical framework that underlies the development of the **IFES-GENIUS-EXT** ontology and its application to university public management. To this end, the main concepts of **Ontology Engineering** are discussed, addressing its structures, types and components, as well as the recent advances in its use in institutional contexts. The review emphasizes the relevance of ontologies as instruments of **semantic integration**, **knowledge governance,** and **organizational transparency**, especially in environments that demand interoperability and data auditing, such as the Federal Institutions of Higher Education (IFES). In addition, the chapter explores national and international experiences that illustrate the role of ontologies and knowledge graphs in the digital transformation of the public sector, preparing the conceptual ground for the ontological engineering methodology presented in the following chapter.

## 3 FUNDAMENTALS OF ONTOLOGY ENGINEERING

Ontology Engineering has established itself as an essential discipline to formally represent knowledge in complex and distributed environments. Its purpose is to make explicit the semantic relationships between concepts, ensuring that people and systems can share a common understanding of a domain (Gruber, 1993; Guarino, 1998). In recent decades, the application of these structures to **public management** has been growing, especially in initiatives aimed at **interoperability, transparency, and intelligent auditing** (Suárez-Figueroa et al., 2012; Diamantini et al., 2025).

In institutional contexts, ontologies allow administrative, financial, and strategic data to be organized in a formal and consistent way, enabling automated queries and logical inferences. They constitute the conceptual basis for the construction of **Knowledge Graphs**, which connect entities, indicators and management processes. This approach is particularly relevant for **Federal Institutions of Higher Education (IFES),** where the diversity of data sources and formats hinders integrated analysis of performance and investments (Lima et al., 2023; Silva et al., 2024).

## 4 STRUCTURE AND COMPONENTS OF ONTOLOGIES

Ontologies are composed of classes (concepts), properties (relations), axioms (logical constraints), and instances (concrete occurrences). The combination of **RDF (Resource Description Framework)** and **OWL (Web Ontology Language)** is vital for modeling intelligent systems, as it allows you to represent detailed knowledge and perform automatic reasoning on data, ensuring consistency and inferring new relationships (Hogan et al., 2021). Validation tools such as **SHACL (Shapes Constraint Language)** reinforce the structural and semantic quality of models (Knublauch, 2017).

In the domain of IFES, these components make it possible to represent and interconnect elements of strategic planning, programs, projects, indicators and budget allocations. Formalization in OWL ensures interoperability and data reuse between different agencies and systems, while SPARQL queries allow dynamic extraction of information relevant to university management (Bittencourt et al., 2019; IFMG, 2025).

### 4.1 TYPES AND LEVELS OF ONTOLOGIES

Ontologies can be classified according to their scope and generality (Guarino, 1998):

- **Top Ontologies:** describe universal and abstract concepts, such as time, space, and event, and are applied as a basis for more specific ontologies.
- **Domain Ontologies:** focus on concepts specific to a certain field, such as public administration or higher education.
- **Task Ontologies:** model activities or processes, such as planning, execution, and monitoring.
- **Application Ontologies:** integrate elements from the previous levels to meet specific contexts.

In the case of **IFES-GENIUS-EXT**, it is an **application ontology**, as it combines elements of domain (university planning and management) and task (monitoring and auditing) to meet the needs of Brazilian IFES. This classification favors conceptual reuse and interoperability between government systems, as recommended by national frameworks such as the **Controlled Vocabulary of Electronic Government (VCGE)** and **DCAT-AP.br** (Brasil, 2019; Ministry of Economy, 2022).

### 4.2 RECENT APPLICATIONS IN PUBLIC MANAGEMENT AND HIGHER EDUCATION

In recent years, several ontologies have been applied to public administration and educational management, evidencing the maturity of the area and the expansion of interoperable initiatives. Among the main ones are:

- **OntoSINAES (2018):** Central Ontology for Brazilian Higher Education Institutions, modeling organizational structure, stakeholders and normative interoperability (Mendonça et al., 2018).
- **DBgoldbr (2018):** Project aimed at transforming open government data into **Linked Open Data**, with a focus on transparency and public data (Nascimento et al., 2018).
- **OntoRS (2023):** Ontology for the Federal Judicial System, Enabling SPARQL Consultations on Legal Decisions and Transparency Audits (Souza & Ribeiro, 2023).
- **IFMG (2025):** Ontology developed to integrate data on school dropout, academic performance, and student assistance, reinforcing the adherence of ontologies to national institutional contexts (IFMG, 2025).

These studies converge in the use of ontologies for **semantic standardization**, **institutional monitoring,** and **knowledge reuse**. IFES-GENIUS-EXT differentiates itself by integrating these principles into the reality of federal universities, creating an infrastructure that connects strategic planning, budget execution, and performance indicators (Bittencourt et al., 2019; Diamantini et al., 2025).

### 4.3 SEMANTIC GOVERNANCE AND INTEROPERABILITY

Semantic governance is a critical aspect in the maintenance of institutional ontologies. Ontologies are living entities, requiring continuous updating and collaborative validation processes (Suárez-Figueroa et al., 2012). The absence of active governance can lead to obsolescence and semantic inconsistency between systems (Oliveira & Lima, 2024). Public institutions also face challenges in terms of technical training, maintenance costs, and cultural resistance to the adoption of semantic technologies (Machado & Nobre, 2022).

Tools and best practices include:

- **Protégé and WebProtégé**, for collaborative modeling and validation;
- **VocBench**, for terminology management and publication of SKOS vocabularies;
- **SHACL**, for automatic verification of structural conformity;
- **OQuaRE and OntoQA**, for ontological quality assessment (Radulovic et al., 2018).

Alignment with national policies — such as the **VCGE, DCAT-AP.br,** and **e-SIC** — ensures interoperability and adherence to the Brazilian digital government strategy (Brasil, 2019; Ministry of Economy, 2022). This semantic governance structure reinforces the institutional viability of IFES-GENIUS-EXT and ensures its long-term technological sustainability.

## 5 METHODOLOGY

This study adopts a **qualitative, exploratory and applied** approach, based on **Ontology Engineering** as a scientific method. Qualitative research seeks to understand complex phenomena in their natural context (Yin, 2018), allowing us to analyze how semantic structures can be applied to university public management. The exploratory character stems from the novelty of the **IFES-GENIUS-EXT ontology**, aimed at modeling institutional knowledge in federal universities. The applied aspect, on the other hand, is manifested in the effective implementation of ontology as an operational component of the framework of intelligent auditing and institutional transparency proposed in this work (Bittencourt et al., 2019; Lima et al., 2023).

Ontology Engineering is used as a method to conceive, formalize and validate conceptual models expressed in formal languages, enabling automated reasoning and interoperability between systems. Its adoption is justified by the need to structure knowledge dispersed in administrative and academic sources, integrating planning data, indicators and budget under the same semantic framework (Guarino, 1998; Suárez-Figueroa et al., 2012).

### 5.1 ONTOLOGICAL ENGINEERING METHODS USED

The development of the **IFES-GENIUS-EXT** ontology was guided by the combination of **the methodologies METHONTOLOGY** (Fernández-López et al., 1997) and **NeOn** (Suárez-Figueroa et al., 2012). The former offers a systematic process for creating ontologies from conception to maintenance, while the latter introduces principles of modularity, reuse, and collaborative development in knowledge networks.

**METHONTOLOGY** defines an iterative cycle composed of stages of **specification**, **conceptualization**, **formalization**, **implementation**, **evaluation** and **maintenance**, ensuring the traceability and consistency of each phase. The **NeOn Methodology, on the other hand,** emphasizes the **reuse of existing ontologies** and **modular integration**, enabling the IFES-GENIUS-EXT model to incorporate concepts from previous ontologies, such as **GENIUS Ontology**, **VCGE, DCAT-AP.br** and **PROV-O**, optimizing interoperability and alignment with national and international standards (Suárez-Figueroa et al., 2012; Nascimento et al., 2018).

The choice to integrate both methodologies allowed the combination of conceptual rigor and practical flexibility, resulting in a process adaptable to the institutional environment of the IFES. This mixed approach also favored the documentation of intermediate artifacts—glossaries, class diagrams, Competency Questions (CQs) tables, and validation scripts—which are essential for scientific transparency and reproducibility.

## 5.2 STAGES OF THE IFES-GENIUS-EXT DEVELOPMENT PROCESS

The development of the ontology followed an iterative cycle structured in six main steps, according to the principles of METHONTOLOGY and NeOn:

1. **Specification:** Definition of the scope and objectives of the ontology, based on the needs of the IFES. The main institutional documents (PDI, LOA, PPA, Management Reports) were surveyed and the stakeholders responsible for the data and processes were identified.
2. **Conceptualization:** Identification and organization of key concepts (*StrategicObjective*, *Program*, *Project*, *BudgetAllocation*, *PerformanceIndicator*), establishing hierarchies and semantic relationships.
3. **Formalization:** Translation of the conceptual structure into logical representations, using OWL and RDF. In this phase, axioms and constraints were created to ensure ontological consistency.
4. **Implementation:** Construction of the ontology in tools such as **Protégé** and **WebProtégé**, with collaborative participation of experts and public managers.
5. **Evaluation:** Application of automatic consistency tests and semantic verification via SHACL, in addition to analysis by domain experts.
6. **Maintenance and Evolution:** Establishment of a semantic governance plan using **VocBench** for terminological control and continuous updating (Oliveira & Lima, 2024).

This process was supported by a set of **Competency Questions (CQs)** that guided the scope of the modeling, such as: "Which programs are linked to a certain strategic objective?" or "Which projects received resources from a specific program in the current year?". The QCs served as completeness metrics and validation guides, ensuring that the ontology answered management questions relevant to the context of IFES (Noy & McGuinness, 2001; Hogan et al., 2021).

## 5.3 TOOLS AND PATTERNS USED

The technical implementation of the ontology used an ecosystem of consolidated tools:

- **Protégé / WebProtégé:** for modeling, documentation and logical verification;
- **VocBench:** for standardization of vocabularies and SKOS publishing;
- **SHACL:** for automatic validation of semantic integrity;
- **SPARQL:** for knowledge retrieval queries and tests;
- **OOPS! and OntoQA:** for the evaluation of good ontological practices.

In addition to the tools, the model followed national and international interoperability standards, highlighting: **VCGE** (Controlled Vocabulary of Electronic Government), **DCAT-**

**AP.br**, **PROV-O**, **SKOS** and **FOAF.** This adherence ensures compatibility with open data portals and institutional catalogs, favoring alignment with the Brazilian Digital Government Strategy (Ministry of Economy, 2022; Zhang et al., 2019).

### 5.4 ONTOLOGY EVALUATION AND VALIDATION

The evaluation of the IFES-GENIUS-EXT ontology combined technical and qualitative criteria. The **OQuaRE** (Radulovic et al., 2018) and **OntoQA** metrics were applied to measure aspects of **completeness**, **coherence**, **concurrency,** and **reusability**. The results showed a high degree of structural consistency and conceptual coverage. The qualitative validation involved reviews conducted by experts from federal universities and institutional data analysts, who evaluated the conceptual clarity and applicability of the model.

The integration between automatic validation (via reasoners and SHACL) and human validation ensured semantic robustness and practical relevance. The process culminated in the generation of a functional RDF repository, capable of feeding intelligent auditing systems and visualization of indicators, confirming the viability of the model as a knowledge governance tool in IFES.

## 6 RESULTS AND DISCUSSION

### 6.1 IMPLEMENTATION OF THE IFES-GENIUS-EXT ONTOLOGY

The implementation of the **IFES-GENIUS-EXT** ontology was conducted in accordance with the methodological cycle established in Chapter 3, using the **OWL 2** language and the **Protégé 5.6.1** development environment. The model was conceived as a **modular extension** of **GENIUS Ontology** (Araujo et al., 2017), preserving the original namespace and ensuring semantic compatibility with the classes and properties of the international educational domain.

The resulting structure comprises **11 classes**, **9 object properties,** and **7 data properties**, all formally declared with axioms of domain, range, and cardinality. This composition seeks a balance between **structural simplicity** and **semantic expressiveness**, in line with the recommendations of Gruber (1993) and Guarino (1998) on the *minimum ontological commitment*.

The core classes represent essential entities of institutional planning: *StrategicObjective*, *Program*, *Project*, *BudgetAllocation,* and *PerformanceIndicator*. Each of them maintains hierarchical and functional relationships consistent with the academic-administrative structures defined in the GENIUS ontology. For example:

Class: StrategicObjective

SubClassOf: genius:OrganizationalGoal

Annotations: rdfs:label "Strategic Objective"@en , "Objetivo Estratégico "@pt

This bilingual annotation standard was adopted systematically, ensuring adherence to the **BCP 47** standard and the **FAIR Interoperability** guideline (Wilkinson et al., 2016). Object properties—such as *isAchievedBy*, *consistsOf*, *hasBudgetAllocation,* and *evaluatedBy*—have been modeled with **OWL constraints** that ensure semantic consistency and enable automated inferences, as validated by HermiT and ELK reasoners.

The ontology was serialized in **Turtle (.ttl)** and **RDF/XML** formats, including Dublin Core metadata and **DCAT v3** vocabulary, ensuring traceability and reuse in different institutional contexts.

## 6.2 APPLIED EVALUATION PROTOCOL

The validation of the model followed the **technical-scientific evaluation protocol** described above, combining quantitative metrics and qualitative verifications inspired by **OntoQA** (Tartir et al., 2005), **OQuaRE** (Duque-Ramos et al., 2011), **OOPS!** (Poveda-Villalón et al., 2012) and **OntoClean** (Guarino & Welty, 2002). The process included six main dimensions:

1. **OWL 2 DL syntactic compliance and profiling** — automatic verification via *ROBOT report* and *HermiT/ELK* reasoners;
2. **Structural quality** — analysis of density of relationships, axioms, and ontological cohesion (*OntoQA-like metrics*);
3. **Semantic/taxonomic quality** — inspection of hierarchies and metaproperties (*OntoClean*);
4. **Lexical and multilingual coverage** — *rdfs:label* and *rdfs:comment exam* in *pt-BR* and *en*;
5. **Adherence to digital government standards** — SKOS/DCAT/CPSV-AP/VCGE mappings;
6. **Readiness for use and inference** —testing SPARQL queries and *Competency Questions* (CQs).

Execution was automated by Python scripts that employed **RDFLib**, **pySHACL** and **SPARQLWrapper**, ensuring full reproducibility. Reports were generated in **CSV** and **TTL formats**, composing a documented *evaluation package*.

## 6.3 STRUCTURAL AND SEMANTIC RESULTS

Structural analysis confirmed syntactic validity and compliance with the **OWL 2 DL** profile. Loading the *ifes-genius-ext.owl* file showed **zero** parsing errors, **no unsatisfiable classes,** and **no redundant axioms**, which demonstrates high formal consistency.

**Table 1**

| OntoQA-like metric | Result | Minimum criteria |
|---|---|---|
| Total Classes | 11 | ≥ 10 |
| Object Properties | 9 | ≥ 8 |
| Data properties | 7 | ≥ 6 |
| Total axioms | 126 | — |
| Domain/Range populated | 100 % | ≥ 90 % |
| Orphan classes | 0 | 0 |
| Valid hierarchical relationships | 100 % | ≥ 95 % |

Lexical coverage showed 100% of labels in English, but absence of complete labeling in Portuguese. This gap was interpreted as an opportunity for improvement, aiming at compliance with the guidelines of the **Controlled Vocabulary of Electronic Government (VCGE)** and with the criterion ≥ *95%* coverage @pt-BR recommended by Duque-Ramos et al. (2011).

The expansion of multilingual labeling, with an emphasis on Portuguese do Brasil (pt-BR), is a priority to ensure adherence to the VCGE and the DCAT-AP.br, expanding the semantic accessibility of the ontology and its adoption by public agents and citizens.

SHACL **validation** — applied to both generic and domain-specific shapes — showed no violations, confirming the adherence of object and data properties to their respective domains and ranges.

The OOPS!-like **automatic checks** identified **no critical pitfall** (such as unlabeled classes, properties without domain or *range*, or taxonomic cycles), reinforcing the coherence of the model.

## 6.4 QUALITY ANALYSIS AND OQUARE SCORECARD

The adapted application of the **OQuaRE framework** resulted in the following mean scores (scale 0–5):

**Table 2**

| Dimension | Score | Interpretation |
|---|---|---|
| **Structural Quality** | 5,0 | Formally solid and consistent model. |
| **Functional Adequacy** | 5,0 | Sufficient classes and properties for the domain of IFES. |
| **Usability** | 3,5 | Penalty for the partial absence of pt-BR labels. |
| **Maintainability** | 4,0 | Modular and easily extendable structure. |

| Dimension | Score | Interpretation |
|---|---|---|
| **Portability/Reusability** | 4,0 | Good compatibility with W3C and VCGE standards. |

The aggregate score (4.3) places IFES-GENIUS-EXT at the **"Very Good"** level according to the OQuaRE taxonomy, indicating maturity for reuse and integration. Compared to academic benchmarks (Fernández et al., 2020; Hubert et al., 2022), the ontology has superior performance in structural consistency and modularity, and equivalent performance in lexical coverage.

## 6.5 CRITICAL DISCUSSION OF RESULTS

The evaluation demonstrates that the **IFES-GENIUS-EXT** complies with the classical principles of clarity, coherence and extensibility (Gruber, 1993; Grüninger & Fox, 1995). Its integration with GENIUS ensures **international interoperability**, while the additional classes expand the representation of **planning, budgeting, and institutional performance**, aspects hitherto absent in educational ontologies.

From the point of view of **public governance**, the model contributes to transparency and **accountability** in Brazilian federal universities, allowing automated consultations and reports on goals and investments. This capability is close to the **Linked Open Data** approaches applied in smart cities (Zhang et al., 2021; Ji et al., 2021), while preserving the specificity of IFES.

The absence of labeling in Portuguese, although it does not compromise semantic coherence, limits reuse by public agents unfamiliar with English terminology. This aspect will be remedied through the systematic application of the **VCGE vocabulary** and terminological standardization according to the DCAT-AP.br guidelines (GovBR, 2023).

In ontological terms, the preliminary **OntoClean** evaluation showed that the Rigidity, Identity, *and* Unit *metaproperties* were correctly assigned to the core classes, ensuring taxonomic consistency.

The OntoClean checklist will be expanded to include operational subclasses and institutional categories, in order to identify possible conceptual overlaps and strengthen the taxonomic coherence of the model.

## 6.6 PRACTICAL IMPLICATIONS AND FUTURE PROSPECTS

The results obtained position **IFES-GENIUS-EXT** as a reusable artifact for **institutional knowledge graph ecosystems**. Its practical application makes it possible to:

- **Strategic indicator dashboards**, powered by SPARQL queries; Chart 1 presents an example of a SPARQL query used to illustrate the extraction of information from the IFES-GENIUS-EXT ontology;
- **Automated budget compliance** audits;
- **Integration with Neo4j, GraphDB and RDF4J platforms**;
- **Interoperability** with public data catalogs (DCAT, CPSV-AP);
- **Future expansion** to use with **Language Models (LLMs)** in explainable analytics (*Explainable AI),* following recent trends (Sarker et al., 2024).

**Table 3**

*Example of SPARQL query on the IFES-GENIUS-EXT ontology*

```
PREFIX ifes: <https://purl.org/ifes-genius-ext#>
SELECT ?budget program
WHERE {
   ?program a ifes:Program .
   ?ifes program:hasBudgetAllocation ?budget .
}
```

Source: Prepared by the authors (2025).

This example demonstrates the automatic extraction of programs and their budgets, highlighting the potential of ontology for automated analysis of institutional planning and budgeting, as well as integration with mood boards and management systems.

## 7 FUTURE PROSPECTS INCLUDE

1. Complete multilingual labelling (≥ 95% en-US);
2. Publish the ontology to Linked Open Data Cloud (LOD) repositories;
3. Incorporate **probabilistic inference modules** for automatic budget allocation recommendations;
4. Develop **semantic dashboards** connected to SIGEPE, SIAFI and SUAP databases; It is planned to publish IFES-GENIUS-EXT in Linked Open Data (LOD) repositories, integrated with these dashboards, allowing public consultations and interoperability with other government catalogs.
5. Expand the model to cover **municipalities** and **federal institutes**, composing an **interconnected SmallCityKG/IFES-KG.**

## 8 SUMMARY OF RESULTS

In summary, the evaluation confirms that **IFES-GENIUS-EXT** has **structural robustness, semantic consistency and interoperability potential**, aligning with digital

government guidelines and the **Sustainable Development Goals (SDGs 11 and 16).** The planned improvements — notably bilingual labeling and taxonomic refinement — will bolster its capacity **to support decision making and public transparency**.

This ontology is consolidated as an **artifact of institutional knowledge engineering**, able to sustain the **strategic monitoring of Brazilian federal universities** and the integration of data between different levels of government.

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