УДК 004.89 + 004.912 DOI: 10.31673/2412-4338.2024.010101

Shapovalov V.B.

National Center "Junior Academy of Sciences of Ukraine", Kyiv

MODULAR ARCHITECTURE OF THE TRANSDISCIPLINARY VIRTUAL STEM-CENTER

This article presents a detailed analysis of a sophisticated software system for a transdisciplinary STEM (Science, Technology, Engineering, and Mathematics) center. The system integrates modules to consolidate ontological and network knowledge bases, create methodological developments, and generate user preference-based recommendations. A notable feature is its capability to rank and filter information based on user-defined rules and present it in an ontological transdisciplinary format. l transdisciplinary format. detailed analysis of a sophisticated software system for a transdisciplinary STEM (Science, Technology, Engineering, and Mathematics) center is presented. The system integrates a series of modules aimed at consolidating ontological and network knowledge bases, creating methodological developments, and generating user preference-based recommendations. A notable feature is its capability to rank and filter information based on user-defined rules, and present it in ontological transdisciplinary format.

The system's architecture is characterized by two principal models: the Information Model and the Functional-Component Model. The Information Model ensures interoperability between popular content management systems like WordPress and the advanced KIT "Polyhedron" system, highlighting the system's applicability and versatility. The Functional-Component Model, on the other hand, offers insights into the interactions and dependencies between various software modules, delineating the system's comprehensive structure and operational dynamics.

A key aspect of the T-STEM center's architecture is its ability to process structured and unstructured data, covering various formats from JSON, XML, OWL, and CSV to PDF, TXT, DOC, and HTML. This flexibility makes the system adaptable to multiple data types and user needs. Structuring of unstructured data is achieved through modules like the "stemua.science Environment," "Recursive Reducer Module," and "Indexer," along with a user interface for structuring educational materials, enhancing its educational functionality.m JSON, XML, OWL, CSV to PDF, TXT, DOC, and HTML. This flexibility makes the system adaptable to various data types and user needs. Structuring of unstructured data is achieved through modules like the "stemua.science Environment," "Recursive Reducer Module," and "Indexer," along with a user interface for structuring educational materials, enhancing its educational functionality.

The system also features specialized subsystems for processing ontologies, such as the "Audit Subsystem," "Alternative Subsystem," and "Analytical System," facilitating user interaction with structured materials through components like "Taxonomic Representation," "Object Representation," and the "Transdisciplinary Cube." This innovative architecture positions the T-STEM center at the forefront of educational technology, offering a robust and user-friendly platform for transdisciplinary studies.

Keywords: *transdisciplinary virtual STEM-center, ontology, modular architecture, ontological structures, information representation, educational technology, data structuring, UML diagrams, automated data processing.*

Шаповалов В.Б.

Національний центр «Мала академія наук України», Київ

МОДУЛЬНА АРХІТЕКТУРА ТРАНСДИСЦИПЛІНАРНОГО ВІРТУАЛЬНОГО STEM-ЦЕНТРУ

У даній статті представлено детальний аналіз складної програмної системи для трансдисциплінарного центру STEM (природничих наук, технології, інженерії та математики). Система об'єднує серію модулів, спрямованих на консолідацію онтологічних та мережевих баз знань, створення методологічних розробок та генерацію рекомендацій, заснованих на уподобаннях користувачів. Особливістю системи є здатність ранжувати та фільтрувати інформацію на основі правил, встановлених користувачем, і представляти її у форматі онтології.

Архітектура системи характеризується двома основними моделями: Інформаційною Моделлю та Функціонально-Компонентною Моделлю. Інформаційна Модель забезпечує взаємодію з популярними системами управління контентом, такими як WordPress, та просунутою системою КІТ "Поліедр", підкреслюючи застосовність та універсальність системи. Функціонально-Компонентна Модель, у свою чергу, надає уявлення про взаємодії та залежності різних програмних модулів, окреслюючи комплексну структуру та оперативну динаміку системи.

Ключовим аспектом архітектури центру T-STEM є його здатність обробляти як структуровані, так і неструктуровані дані, охоплюючи широкий спектр форматів від JSON, XML, OWL, CSV до PDF, TXT, DOC та HTML. Ця гнучкість робить систему адаптивною до різних типів даних та потреб користувачів. Структурування неструктурованих даних досягається за допомогою модулів, таких як "Середовище stemua.science", "Модуль Рекурсивного Редуктора" та "Індексатор", а також за допомогою користувацького інтерфейсу для структурування навчальних матеріалів, підвищуючи його освітню функціональність.

Система також включає спеціалізовані підсистеми для обробки онтологій, такі як "Підсистема Аудиту", "Підсистема Альтернатив" та "Аналітична Система", полегшуючи взаємодію користувачів зі структурованими матеріалами через компоненти, такі як "Таксономічне Представлення", "Об'єктне Представлення" та "Трансдисциплінарний Куб". Ця інноваційна архітектура виносить центр T-STEM на передову освітньої технології, пропонуючи надійну та зручну платформу для трансдисциплінарних досліджень.

Ключові слова: *трансдисциплінарний віртуальний STEM-центр, онтологія, модульна архітектура, онтологічні структури, представлення інформації, освітні технології, структурування даних, діаграми UML, автоматизована обробка даних.*

1. Introduction

The increasing integration of Information Technology (IT) in various fields, particularly in STEM education, has opened new avenues for enhancing learning experiences and operational efficiency. As the STEM education landscape evolves, IT systems, such as Intelligent Tutoring Systems and high-tech tools, have shown significant potential in revolutionizing educational methodologies. Furthermore, the development of decision-making systems underscores the critical role of IT in managing and processing big data. These advancements highlight the necessity of a sophisticated approach toward the consolidation of educational resources, emphasizing the need for a well-structured and efficient system that leverages the power of big data and IT in transdisciplinary methods. and efficient system that leverages the power of big data and IT in transdisciplinary systems.

Research in the field of STEM education has highlighted the potential of ICT in engaging students and enhancing their learning experiences [1]. However, the use of technology in STEM education is still essentially provisional, with both teachers and students mainly using it reproductively as consumers of information. To address this, a balanced approach that combines technology-based teacher-led and student-centered strategies has been proposed [3]. This is particularly important in the context of declining interest in STEM subjects, as seen in Romania [4]..

A range of studies have explored the intersection of STEM education and IT systems. Kireš (2019) emphasizes the need for innovation in STEM education, particularly through the use of IT, to meet the demands of the information society. Fletcher (2018) underscores the potential of Intelligent Tutoring Systems (ITS) in providing individualized STEM instruction with a focus on national defense. Lakshminarayanan (2015) discusses the various high-tech tools that can enhance STEM education, including virtual reality, flipped classrooms, and cloud computing Durovic (2019) proposes a model for an online evaluation system in STEM education, which aims to motivate students and improve learning outcomes. These studies collectively highlight the potential of IT systems in transforming and enhancing STEM education [8].

A range of studies have explored the development of decision-making systems based on the ontology of the choice problem. Stryzhak (2021) emphasizes the need for a system that can process unstructured information and integrate it systematically, proposing an ontology of the problem of rational choice [9]. Startseva (2019) applies this concept to career choice, using an ontology to automate decision support processes[10]. Lytvyn (2018) introduces the idea of adaptive ontologies, which can weigh concepts and relations based on their importance in a given domain, and applies this to the development of intelligent decision support systems[11]. Baclawski (2017) further extends this work by developing a formal framework for decision making, which includes an ontology that classifies data and reasoning modes, and addresses practical concerns such as time, activity recording, and provenance[12].

The development of an oceanographic databank based on an ontological model is a key focus in the literature. Stryzhak (2021) proposes a databank that uses an ontological representation of information arrays and an ontology-defined interface[13]. Almendros-Jiménez (2013) extends this work by presenting a framework for ocean satellite image classification based on ontologies, which allows for the sharing of data between applications [14]. This approach is further supported by Milward (2005), who presents an ontology-based interactive information extraction system for scientific abstracts [15]. The use of ontologies in representing information is also explored by Globa (2020), who develops an ontological model for scientific institutions [16]. These studies collectively highlight the potential of ontological models in enhancing the representation and accessibility of scientific information.

A range of studies have explored the use of architecture ontologies in education. Gascueña (2016) proposed an authoring tool that uses domain, sequencing, and content-repository ontologies to personalize educational materials [17]. Laoufi (2011) implemented an ontology-based architecture for knowledge management in higher education, creating a repository of resources for learning and research [18]. Stancin (2020) conducted a literature review, highlighting the increasing use of ontologies in education, particularly for curriculum modeling, learning domain description, and e-learning services [19]. Motz (2005) applied ontologies to an e-learning project, using them to retrieve and manage educational resources based on user cultural aspects [20]. These studies collectively demonstrate the potential of architecture ontologies in enhancing the personalization, organization, and retrieval of educational materials.

However, all those studies not disrobe and justify the complex system of consolidation of educational resources. However, previously, the studies were devoted to consolidation of big data including related to education [21–23]. This ensures communication between stakeholders of educational process and ensures personalization of education though ensuring fullness of contexts of terms in transdisciplinary systems [22].

Therefore, this study aims substantiating of architecture of virtual transdisciplinary STEM-center based on modern understanding of consolidation principles.

2. Architectural design and functional dynamics of the transdisciplinary Stem-center software system

The software system of the transdisciplinary STEM center is a set of modules designed for the consolidation of ontological and network knowledge bases, creation of methodological developments, and generation of recommendations based on user preferences. The system performs ranking and filtering of information according to user-defined rules, presenting it in the form of an ontological structure [24, 25], and subsequently, in a transdisciplinary representation.

The services of the transdisciplinary STEM center implement structuring, classification, and semantic analysis of information resources, which reflect a multitude of subject areas studied by the learner.

From the perspective of software engineering, the STEM center is considered as a set of descriptions represented in the form of mathematical models, formalisms, and modeling techniques[26, 27].

The structure of mathematical models of such software entities includes the following models [26, 27]:

1. Information model;
2. Functional-component model.

3. Information model of the software system of the transdisciplinary STEM-center

The generalized information model of the system ensures interoperability between the widely used WordPress content management system, which currently accounts for 40% of all internet resources and 64% among content management systems, and the innovative information representation in the KIT "Polyhedron" system.

Considering the proposed solutions (which can be represented by a finite set of software modules PR) are integrated into the KIT "Polyhedron" system, we apply the generalized information model used (1):

$$\Pi_R = \sum_{i=1}^{n} \Pi_{R_i} \cup \Pi_T \quad (1)$$

Thus, the interpretation of the integration of the functions of all the software modules of the system is realized. To achieve the overall goal of creating a transdisciplinary laboratory of the STEM center, the union of the sets of functions of each of the software modules into a single functional system was ensured. The IT platform KIT "Polyhedron," based on the IT technology TODOS, in turn, is a multifunctional system with a set of functions described previously.

Information model for templating information resources of the T-Stem center

The information model is used to represent and describe information flows, data structures, and software services in the T-STEM environment.

The generalized information model of T-STEM S_R takes the form (2). It is represented by a certain finite set of software services S_{R_i} that are consolidated in the T-STEM environment based on the set of services of the KIT "Polyhedron" (2):

$$S_R = \sum_{i=1}^{n} S_{R_i} \quad (2)$$

In general, the assembly of modules in the virtual STEM center is represented by equation (3).

$$S_R = \{S_{CI}, S_{DI}, S_{SC}, S_{UC}, S_{TT}\} \quad (3)$$

S_{CI}– a service responsible for creating information used by the virtual STEM center. The set of functions of this module is represented by equation (4).

$$S_{CI} = \{F_1^{S_{CI}}, F_2^{S_{CI}}, F_3^{S_{CI}}, F_4^{S_{CI}}, F_5^{S_{CI}}, F_6^{S_{CI}}, F_7^{S_{CI}}\} \quad (4)$$

Its functions include:

$F_1^{S_{CI}}$– storing information received from system users in the information storage.

$F_2^{S_{CI}}$– filtering information received from users.

$F_3^{S_{CI}}$– structuring information received from the user.

$F_4^{S_{CI}}$– generating input fields according to the defined template rules.

$F_5^{S_{CI}}$– generating content categories.

$F_6^{S_{CI}}$– preserving information formatting.

$F_7^{S_{CI}}$ – using formulas in content creation.

S_{DI}– a service responsible for the correct display of information. This service performs the following functions as shown in equation (5).

$$S_{DI} = \{F_1^{S_{DI}}, F_2^{S_{DI}}, F_3^{S_{DI}}\} \quad (5)$$

$F_1^{S_{DI}}$– forming a request to the information resource.

$F_2^{S_{DI}}$– forming a visual display using the obtained data.

$F_3^{S_{DI}}$– ensuring interactive viewing of information.

S_{SC}– a service responsible for the security and stable operation of the virtual STEM center. The set of functions of this module is as follows (6).

$$S_{sc} = \{F_1^{S_{sc}}, F_2^{S_{sc}}, F_3^{S_{sc}}\} \quad (6)$$

Its functions include:

$F_1^{S_{sc}}$ – blocking unauthorized access to the virtual STEM center.

$F_2^{S_{sc}}$ – protection against network attacks.

$F_3^{S_{sc}}$ – filtering dangerous inclusions in the information storage and distortion of information system files.

S_{MTC}– a service responsible for the model of information representation of criteria in the ranking task. The set of functions of this module is as follows (7).

$$S_{UC} = \{F_1^{S_{UC}}, F_2^{S_{UC}}, F_3^{S_{UC}}, F_4^{S_{UC}}\} \quad (7)$$

Its functions include:

$F_1^{S_{UC}}$– creating and editing users of the virtual STEM center.

$F_2^{S_{UC}}$– creating roles for users.

$F_3^{S_{UC}}$ – granting permissions to users according to their roles.

$F_4^{S_{UC}}$– storing information about users.

S_{TT}– a service responsible for data exchange with components of the KIT "Polyhedron" information technology (8).

$$S_{TT} = \{F_1^{S_{TT}}, F_2^{S_{TT}}, F_3^{S_{TT}}, F_4^{S_{TT}}\} \quad (8)$$

$F_1^{S_{TT}}$– generating informational objects and their properties for further processing.

$F_2^{S_{TT}}$– converting the obtained informational objects into a structured format.

$F_3^{S_{TT}}$– using structured data to generate ontological hierarchized graphs.

$F_4^{S_{TT}}$– receiving processed information by the KIT "Polyhedron" system.

4. Information model of the subset of interaction modules of information resources with kit "polyhedron" used in data systematization in the virtual STEM-center

Most modules of KIT "Polyhedron" are utilized in the virtual STEM center. Within the composition of KIT "Polyhedron," there is a multifunctional editor capable of saving information in various formats, as well as an expandable set of converters for transforming taxonomies into data formats not supported by the editor. Additionally, KIT "Polyhedron" is equipped with an expandable software subsystem for displaying ontologies, on the basis of which modules for transdisciplinary representation and the formation of laboratories in the virtual STEM center can be created.

The following modules can be considered integrated into KIT "Polyhedron":

A service for displaying information in the form of an ontograph;

Utilization of alternatives for filtering semantic characteristics;

A service for processing information using a ranking algorithm.

In general, the subset Π_T^R of KIT "Polyhedron" modules used in the process of forming the STEM center can be represented by the structure (9).

$$\Pi_T^R = \{\Pi_{ГД}, \Pi_{ТБ}, \Pi_{ТК}, \Pi_{СХ}, \Pi_{РТ}, \Pi_{ТДП,}\Pi_{ДК}\} \quad (9)$$

Some KIT "Polyhedron" modules are created to perform only one specific function, particularly:

$\Pi_{ГД}$– a service designed for displaying ontology in the form of an ontological catalog of methodologies;

$\Pi_{ГБ}$– a service representing a list of ontology objects in table form;

$\Pi_{ГК}$– a service for displaying ontology in the form of an ontograph;

$\Pi_{СХ}$ – a service for displaying ontology in the form of modified ranking.

$$S_{CX} =< S_1^{CX}, S_2^{CX}, S_3^{CX}, S_4^{CX}, S_5^{CX} > \quad (10)$$

Functions of the module:

S_1^{CX}– storing ontologies open for public access;

S_2^{CX}– storing personal ontologies of the user;

S_3^{CX} – access control to ontologies;

S_4^{CX}– providing a software interface for reading and writing ontologies;

S_5^{CX}– storing metadata of ontologies.

$\Pi_{РТ}$– a service for generating ontology from unstructured data arrays obtained from the network. Functions of the module:

$$S_{CX} =< S_1^{РТ}, S_2^{РТ}, S_3^{РТ}, S_4^{РТ}, S_5^{РТ}, S_6^{РТ} > \quad (11)$$

$S_1^{РТ}$ – reading and writing ontologies in XML format;

$S_2^{РТ}$¬ – adding and removing objects;

$S_3^{РТ}$– adding and removing links between objects;

$S_4^{РТ}$– editing attributes of objects;

$S_5^{РТ}$– automatic placement of objects in the workspace;

$S_6^{РТ}$– filtering the set of displayed objects.

$\Pi_{ТДП}$ – a service implementing transdisciplinarity of unstructured data from various information and telecommunication systems in an ontological environment:

$$S_{CX} =< S_1^{ТДП}, S_2^{ТДП}, S_3^{ТДП} > \quad (12)$$

Functions of the module:

$S_1^{ТДП}$– reading data from educational information and telecommunication systems;

$S_2^{ТДП}$– forming transdisciplinary links between vertices of structured data, obtained data from various ITS;

$S_3^{ТДП}$– using modules of KIT "Polyhedron" to provide information management functions regarding STEM center resources.

$\Pi_{ДК}$ – a block of auxiliary converters, containing a software interface for creating subprogram-converters, as well as a basic set of such subprograms. The set of functions of this module is as follows (13), where $S_1^{ДК}$– providing a software interface for subprogram-converters; $S_{x_i y_i}^{ДК}$– a subprogram-converter from format χ_i to format y_i; $n_{ДК}$– the total number of available subprogram-converters.

$$S_{ДК} =< S_1^{ДК}\{S_{x_i y_i}^{ДК} | i \in [1; n_{ДК}]|\} > \quad (13)$$

Available are main converters for data transformation, particularly from CSV to XML format, from JSON to XML, from XML to CSV, and from HTML to text file. Additionally, there are specialized converters that ensure integration with important programs, including a converter from HTML created by Microsoft Office to text format, as well as a converter from XML to CSV format that can be read in MySQL.

5. Functional component model of the software system for transdisciplinary information representation

The functional-component model is employed to represent interactions, relationships, and dependencies of software modules, as well as for a detailed description of the system components. The generalized model for the software complex of transdisciplinary representation in the STEM center can be represented by the structure (3.14).

$$S_R =< M_D, M_S, M_P, M_c, P_0(M_D, M_s) > \quad (14)$$

Elements included in this model:

M_D– the model defining the system behavior;

M_S– the model defining the structure of the system;

M_p – the model defining the structure of software entities;

M_C – the model (scheme) of components of the software system;

$P_0(M_D, M_s)$– – the predicate of the system's integrity.

The model of the system behavior has the structure (3.15).

$$M_D =< d_{use}, d_{act}, d_{seq} > \quad (15)$$

It includes:

d_{use} – a set of UML use case diagrams of the system for transdisciplinary information representation.

d_{act} – a set of UML activity diagrams of the system for transdisciplinary information representation.

d_{seq} – a set of UML interaction diagrams of the system for transdisciplinary information representation.

6. Comprehensive Architecture of the T-STEM Center: Integration of KIT Polyhedron Modules and Advanced Structuring Components

The architecture of the T-STEM center consists of existing modules of KIT "Polyhedron", integration components that represent a REST application programming interface, user communication interfaces, and specially developed structuring modules. The system is capable of processing both structured (such as in JSON, XML, OWL, CSV formats) and unstructured data sets (such as in PDF, TXT, DOC, HTML formats). Pre-structured data sets can be used directly for processing in the taxonomy editor and viewed in the "Taxonomy Viewer" component of the "Editing and Display Interface for Structured Information" module. The structured information processed in this module is transferred to the "KIT Polyhedron Controller" component of the "KIT Polyhedron Central Server" module and stored in the "Ontology Library" component. Unstructured data sets are subject to structuring before being saved in the components of the "KIT Polyhedron Central Server" module. Structuring can be carried out in the "stemua.science Environment", "Recursive Reducer Module", and "Indexer" modules (regarding the indexing of materials relative to structured taxonomies). For the purpose of structuring, the user interface "stemua.science Material Editor" can be used, where users fill in the form for structuring educational materials. These materials are stored in the "stemua.science Database" component and, using the "REST API Exchange Subsystem" components, are transmitted to the "Ontology Library" component of the "KIT Polyhedron Central Server" module. Unstructured natural language text can be automatically processed in the "Recursive

Reducer" module, which, through the "Reduction Rule Database" component, ensures structuring and subsequent storage in the "Ontology Library" component of the "KIT Polyhedron Central Server" module. The indexer provides interconnections between existing structured ontological materials and other unstructured ones, particularly in the form of a search prism. For this, data indexed in the "Indexer" component can be transmitted to the "Structuring Subsystem Controller" component of the "Recursive Reducer" module using the "REST API Exchange Subsystem" module or directly from the "Indexer" component applied to structured data stored in the "Ontology Library" component of the "KIT Polyhedron Central Server" module.

All structured materials of the T-STEM center are visualized and processed in the "Auxiliary Center" and "KIT Polyhedron Representation Interfaces" modules. Thus, T-STEM ontologies are processed in the "Audit Subsystem", "Alternative Subsystem", and "Analytical System" components. T-STEM center users can interact with structured materials using the "Taxonomic Representation", "Object Representation", and "Transdisciplinary Cube" components. The architecture of the T-STEM center is presented in Fig. 1.

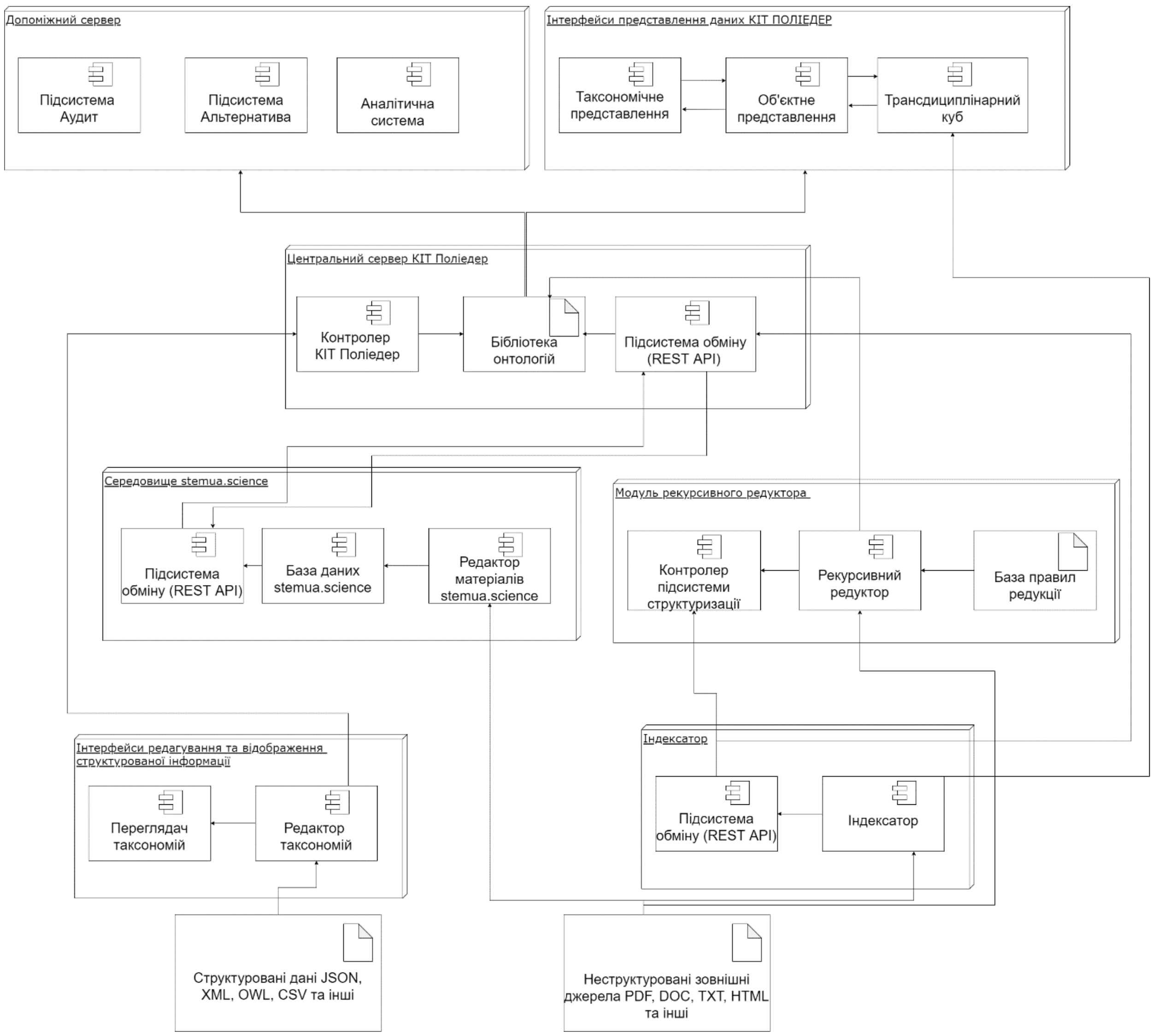

Fig.1. The architecture of the T-STEM center

7. Conclusions

The culmination of this study on the modular architecture of a transdisciplinary virtual STEM-center reveals a multifaceted system designed to interface seamlessly with existing content management frameworks, particularly WordPress, and the KIT "Polyhedron." The system distinguishes itself through its ability to rank, filter, and present information in a transdisciplinary context, driven by user-defined specifications. It adeptly processes a spectrum of data formats, both structured and unstructured, demonstrating a high degree of adaptability and user-centric customization. Through its innovative integration of modules for data structuring, ontology processing, and user interaction—facilitated by components like the "Taxonomic Representation" and "Transdisciplinary Cube"—the system provides a dynamic platform for educational enhancement. The study underscores the potential of such a system in revolutionizing educational methodologies and contributing to a more engaged learning environment. This is achieved by fostering a transdisciplinary approach that transcends traditional educational boundaries, thus offering a blueprint for future educational technology frameworks that cater to the evolving landscape of STEM education.

References

1. Ferreira, C., Neves, P., Costa, C., et al. Socio-constructivist teaching powered by ICT in the STEM areas for primary school: 2017 12th Iberian Conference on Information Systems and Technologies (CISTI), IEEE, June.17. P. 1–5.

2. Birzina, R., Pigozne, T. Technology as a Tool in STEM Teaching and Learning30.April.20. P. 219–227.

3. Terzieva, V., Todorova, K., Pavlov, Y., et al. Blending Technology-based Teacher-led and Student-centered Approaches in STEM Education: Proceedings of the 21st International Conference on Computer Systems and Technologies, New York, NY, USA, ACM, 19.June.20. P. 313–319.

4. Istrate, O., Mironov, C., Popovici, A. The use of technology in stem education. an empirical research. Revista de Pedagogie - Journal of Pedagogy. 2019. Vol. LXVII, No. 1. P. 73–91.

5. Kires, M., Sveda, D., Jeskova, Z., et al. Key innovation concepts of STEM education driven by IT Academy project: 2019 17th International Conference on Emerging eLearning Technologies and Applications (ICETA), IEEE, November.19. P. 378–382.

6. Fletcher, J. D. Comments and reflections on ITS and STEM education and training. International Journal of STEM Education. 2018. Vol. 5, No. 1. P. 16.

7. Lakshminarayanan, V., McBride, A. C. The use of high technology in STEM education.

8. Durovic, G., Holenko Dlab, M., Hoic-Bozic, N. A Model of an Online Evaluation System for STEM Education: 2019 42nd International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), IEEE, May.19. P. 677–680.

9. Stryzhak, O., Horborukov, V., Prychodniuk, V., et al. Decision-making system based on the ontology of the choice problem. Journal of Physics: Conference Series. 2021. Vol. 1828, No. 1. P. 0–7.

10. Startseva, E., Grimaylo, A., Chernyahovskaya, L., et al. Ontology Based Decision Support in Career Choice: 2019 XXI International Conference Complex Systems: Control and Modeling Problems (CSCMP), IEEE, September.19. P. 182–186.

11. Lytvyn, V., Vysotska, V., Dosyn, D., et al. Methods of Building Intelligent Decision Support Systems Based on Adaptive Ontology: 2018 IEEE Second International Conference on Data Stream Mining & Processing (DSMP), IEEE, August.18. P. 145–150.

12. Baclawski, K., Chan, E. S., Gawlick, D., et al. Framework for ontology-driven decision making. Applied Ontology. 2017. Vol. 12, No. 3–4. C. 245–273.

13. Stryzhak, O., Prykhodniuk, V., Popova, M., et al. Development of an Oceanographic Databank Based on Ontological Interactive Documents BT - Intelligent Computing Cham, Springer International Publishing, 21. P. 97–114.

14. Almendros-Jimenez, J. M., Domene, L., Piedra-Fernandez, J. A. A Framework for Ocean Satellite Image Classification Based on Ontologies. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. 2013. Vol. 6, No. 2. P. 1048–1063.

15. Milward, D., Bjäreland, M., Hayes, W., et al. Ontology-Based Interactive Information Extraction From Scientific Abstracts. Comparative and Functional Genomics. 2005. Vol. 6, No. 1–2. C. 67–71.

16. Globa, L., Novogrudskaya, R., Zadoienko, B., et al. Ontological Model for Scientific Institutions Information Representation: International Conference on Problems of Infocommunications. Science and Technology (PIC S&T), IEEE, 06.October.20. P. 255–258.

17. Gascuena, J. M., Fernández-Caballero, A., Gónzalez, P. An authoring architecture for annotating educational contents : Domain, sequencing and content-repository ontologies. ICEIS 2007 - 9th International Conference on Enterprise Information Systems, Proceedings. 2007. Vol. HCI. P. 53–60.

18. Laoufi, A., Mouhim, S., Megder, E. H., et al. An ontology based architecture to support the knowledge management in higher education: 2011 International Conference on Multimedia Computing and Systems, IEEE, April.11. P. 1–6.

19. Stancin, K., Poscic, P., Jaksic, D. Ontologies in education – state of the art. Education and Information Technologies. 2020. Vol. 25, No. 6. P. 5301–5320.

20. Motz, R., Guzmán, J., Deco, C., et al. Applying Ontologies to Educational Resources Retrieval driven by Cultural Aspects 1. Journal of Comptuer Science & Technology. 2005. Vol. 5, No. 4. P. 279–284.

21. Stryzhak, O., Dovgyi, S., Popova, M., et al. Transdisciplinary Principles of Narrative Discourse as a Basis for the Use of Big Data Communicative Properties: Advances in Intelligent Systems and Computing. 2021.

22. Stryzhak, O., Gorborukov, V., Dovgyi, S., et al. Transdisciplinary Principles of Consolidation: Information and Communication Technologies and Sustainable Development. 2023.

23. Nadutenko, M., Prykhodniuk, V., Shyrokov, V., et al. Ontology-Driven Lexicographic Systems: Advances in Information and Communication. FICC 2022. Lecture Notes in Networks and Systems. Cham, Springer, 2022.

24. Приходнюк, В. ., Стрижак, О. Є., Лебідь, О. Г. Онтологічне представлення функціональності систем. Екологічна безпека та природокористування. 2016. Випуск. 3– 4 (22). С. 5–23.

25. Приходнюк, В. ., Стрижак, О. Є. Множинні характеристики онтологічних систем: Математичне моделювання в економіці, К. , НАН України Інститут телекомунікацій і глобального інформаційного простору, Інститут економіки та прогнозування, Інститут кібернетики ім. В. М. Глушкова, 17. P. 47–61.

26. Broy, M. Mathematical Methods in System and Software Engineering: NATO ASI SERIES F COMPUTER AND SYSTEMS SCIENCES, Berlin , Springer, 97. P. 271–312.

27. Broy, M. Mathematical System Models as a Basis of Software Engineering: Berlin: Springer, 1995. 292P.