CONCEPTUAL MODEL FOR THE FORMULATION OF STRATEGIC GUIDELINES FOR ENGINEERING EDUCATION

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Abstract: *Digital Transformation demands changes in engineering programs. Although the 2019 national curricular guidelines drive a transformation process in Engineering Education, universities still need the appropriate tools to train professionals for Industry 4.0 and Society 5.0. This work proposes a conceptual model to guide the updating of programs, considering the Digital Transformation scenario. The conceptual model was designed with the support of a Knowledge Engineering tool and validated by Engineering Education experts.*

Keywords: Engineering Education; Educational Technologies; Smart Education; Conceptual Model; Lightweight CommonKADS.

Resumo: *A Transformação Digital demanda mudanças nos cursos de engenharia. Apesar das diretrizes curriculares nacionais de 2019 conduzirem a um processo de transformação na Educação em Engenharia, as universidades ainda carecem de ferramentas apropriadas para formar profissionais para a Indústria 4.0 e Sociedade 5.0. O objetivo do trabalho é propor um modelo conceitual para orientar a atualização dos cursos, levando em consideração o cenário da Transformação Digital. O modelo conceitual foi projetado com o suporte de uma ferramenta da Engenharia do Conhecimento e validado por especialistas em Educação em Engenharia.*

Palavras-chave: Educação em Engenharia; Tecnologias Educacionais; Smart Education; Modelo Conceitual; Lightweight CommonKADS.

Resumen: *La Transformación Digital demanda cambios en los programas de ingeniería. A pesar de que las directrices curriculares nacionales de 2019 conducen a un proceso de transformación en la Educación en Ingeniería, las universidades aún carecen de herramientas apropiadas para formar profesionales alineados con las demandas de la Industria 4.0 y la Sociedad 5.0. El objetivo de este trabajo es proponer un modelo conceptual para guiar la actualización de los programas de ingeniería, teniendo en cuenta el escenario de la Transformación Digital. El modelo conceptual fue diseñado con el apoyo de una herramienta de Ingeniería del Conocimiento y validado por expertos en Educación en Ingeniería.*

Palabras clave: Educación en Ingeniería; Tecnologías Educativas; Smart Education; Modelo Conceptual; Lightweight CommonKADS.

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1 INTRODUCTION

Digital Transformation in education aims to use digital technologies to create or modify teaching and learning processes, student culture, and experiences in the digital society. In a way, the new National Curricular Guidelines (NCGs) (Oliveira, 2019) anticipate revising pedagogical program projects, seeking the transformation of Brazilian engineering education.

Engineering Education involves training students in competencies, combining knowledge, application, and practical experience. However, for training to be effective, engineering schools need to invest in educational technologies and adopt competency formation models. Smart Education (Makarova et al., 2019) is an approach that combines best competency formation practices with modern educational technologies. It includes a development strategy, adopting “smart” environments and technologies, and seeks educational outcomes aligned with a new generation of interconnected students and professional communities. This can be considered Education 4.0.

Education 4.0 goes beyond knowledge transmission and the adoption of educational technologies. For competency formation, knowledge must be applied skillfully in the professional environment and with appropriate behavior (Das et al., 2020). In this sense, a taxonomy (World Economic Forum, 2021) defines the concept of competency as "the collection of professional skills, knowledge, attitudes, and physical abilities that enable an individual to hold job positions." On the other hand, an educational model for the horizon of 2030 (OECD, 2019) goes beyond knowledge, skills, and attitudes. The OECD proposal includes the need for professionals to have values. In this model, students learn to face the challenges of current changes and collaborate to create a better future. Education 4.0 (Fisk, 2017) involves education at various times and places, with personalized learning, allowing students to progress at their own pace and choose learning styles and paths. In Education 4.0 (World Economic Forum, 2023), the teacher's role changes from a knowledge holder to a mentor, placing the student at the center of the process.

The report "The global state of the art in Engineering Education" (Graham, 2018) emphasizes that leading institutions in Engineering Education already develop student-centered educational projects. They apply learning-based methodologies with intensive use of technology, stimulating entrepreneurship without forgetting the rigor in engineering fundamentals. On the other hand, emerging leaders are working with proposals for new programs and meeting local needs and constraints through multidisciplinary programs with new educational support tools focused on innovation and aligned with the OECD model.

1.1 REAL-WORLD RESEARCH PROBLEM

The report "Education in Brazil: an international perspective" (OECD, 2021) says improvements are needed in higher education. The report criticizes competency assessment through *ENADE* (National Student Performance Exam), stating that the general assessment component is not aligned with program contents, weakening competency-based training. This results in newly graduated engineers without the competencies to deal with the challenges of Industry 4.0 and Society 5.0, affecting the competitiveness of companies and society (Brasil, 2020).

Additionally, universities do not listen to industry demands, and the latter does not seek to approach and communicate its needs (Shafeek, 2019). Another report (Frank et al., 2021) highlights the lack of specialization in educational institutions and the reduced attractiveness of students to STEM areas (Science, Technology, Engineering, and Mathematics).

Another concern is that Engineering Education has not kept up with rapid innovations in business processes, failing to update knowledge and learning methodologies. The lack of transformative changes in the educational system creates a gap between technology and education, resulting in "social pain" (OECD, 2019). Specifically, in Engineering Education, there is a decrease in the number of interested students (MEC & INEP, 2021), low participation of minority groups (Frank et al., 2021), high dropout rates (Oliveira, 2019), lack of financial resources, and inadequacy of the curriculum matrix (CN-DCNs, 2020).

Given these concerns, it is necessary to formulate strategic guidelines to align the adoption of educational technologies with best practices in Smart Education. This aims to develop competencies in Digital Transformation. These strategic guidelines can contribute to improving the training of engineers. However, at the organizational level of engineering schools, there are no effective strategic guideline models to guide the design and updating of programs in forming competencies that meet the demands of Industry 4.0 and Society 5.0.

Therefore, the research problem is defined by the following question: *How can engineering schools strategically support forming student competencies that align with the demands of digital transformation?*

1.2 OBJECTIVE

The general objective of this work is to propose a conceptual model for formulating strategic guidelines in designing and updating engineering programs according to the Digital Transformation scenario.

Applying the conceptual model to engineering programs is expected to contribute to training professionals qualified to face the challenges and opportunities offered by Digital Transformation, reducing the harmful effects identified in the research problem.

Initially, an analysis of how Engineering Education relates to Education 4.0 (Diogo et al., 2023) was conducted. Then, the conceptual model was designed using a Knowledge Engineering tool. To evaluate the feasibility and consistency of the model, it was implemented on a computational platform and tested with experts in Engineering Education.

1.3 METHODOLOGY AND SUPPORT TOOLS

This work followed the steps suggested by the Design Science Research methodology (Dresch et al., 2015), culminating in conceptual model design. DScaffolding (Contell et al., 2017) was also used as a support tool for the Problem Identification and Problem Understanding phases in DSR.

The fundamentals and conceptual basis were extracted from a Systematic Literature Review (SLR) (Diogo et al., 2023), which aided in Artifact Identification and Problem Class Configuration.

In the Proposal of Artifacts for Solving a Specific Problem phase and the Design of the Selected Artifact phase, the Lightweight CommonKADS (Surakratanasakul, 2017) was used as a Knowledge Engineering tool to design the conceptual model. The Artifact Development was done with its implementation on the Microsoft 365 SharePoint computational platform.

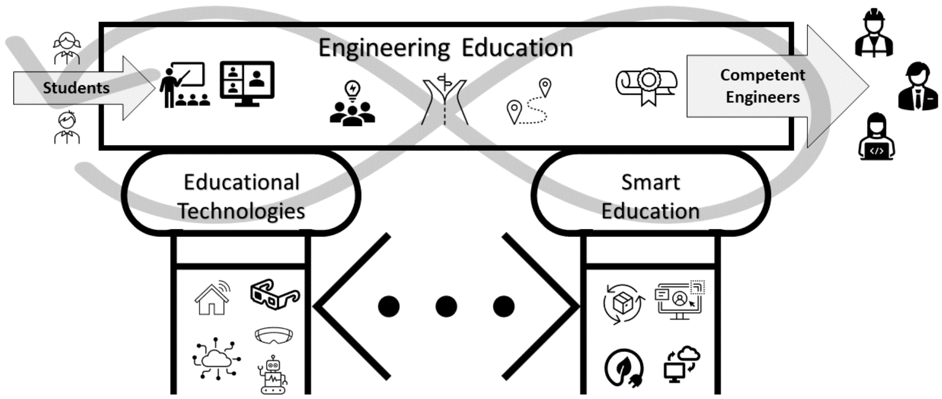
Finally, in the Artifact Evaluation phase, semi-structured interviews were conducted with experts in Engineering Education.

2 BRIDGE TO ENGINEERING EDUCATION: EDUCATIONAL TECHNOLOGIES AND SMART EDUCATION

Educational Technologies, Engineering Education, and Smart Education were the three most used keywords in the publications analyzed during an SLR (Diogo et al., 2023). It was found that the three terms are closely related since Engineering Education needs to be supported by Smart Education and Educational Technologies to meet training requirements in the context of Digital Transformation (Figure 1).

Smart Education covers methodologies based on active learning, intelligent tools for academic support, stakeholder engagement, and other actions to develop competencies aligned with Digital Transformation (Borg et al., 2019). In Smart Education, there is both the dissemination and co-creation of knowledge and the development of professionals, attitudes, and personal values. In turn, Educational Technologies work connected to Smart Education through data analysis and artificial intelligence for organizational knowledge management. Almost all the pillars of Industry 4.0 support the new Educational Technologies. Meanwhile, Smart Education is anchored in Educational Technologies and tools, methods, and actions for effective competency formation (Dneprovskaya & Shevtsova, 2018).

Figure 1 – The bridge of Engineering Education supported by Educational Technologies and Smart Education



Source: Diogo et al. (2023)

Smart Education contributes to personalized learning, meaning each student has personal and professional goals (Tikhomirov et al., 2015). However, another type of personalized learning should be considered: Students choose the educational tools that best suit them at their own pace (Uskov et al., 2019). Smart Education is considered an evolution from e-learning (Makarova et al., 2019). The latter relied on ICTs for content dissemination in the traditional teaching model, with the teacher as the central part of the teaching-learning process. On the other hand, Smart Education can be applied in face-to-face, blended, distance, and simultaneous learning. It incorporates modern Educational Technologies and methodologies based on active learning, placing the student at the center of learning. They train by competencies, applying knowledge with skills, attitudes, and values. Moreover, Smart Education relies on Artificial Intelligence for teaching and managing university operations. Due to the opportunities, students can study wherever and at any time. Smart Education makes Engineering Education less expensive, as university infrastructure is reduced since part of the technology is transferred to the environment where the student is, with them assuming operational costs.

However, Smart Education can be considered inclusive, as it reaches international distances and learners who previously did not have easy access to educational resources. Costs for commuting, housing, and food are reduced. Time use is also optimized. On the other hand, it is also exclusive, as only students and universities with access to technology will be included in the context of Smart Education.

In this scenario, it is evident that the number of possibilities and opportunities is high. Moreover, there is a noticeable absence of models formulating strategic guidelines for adopting Educational Technologies and Smart Education, especially in Engineering Education. Therefore, a Knowledge Engineering tool can help design a conceptual model that guides the adoption of the pillars of modern Engineering Education.

3 LIGHTWEIGHT COMMONKADS

Lightweight CommonKADS (Surakratanasakul, 2017) is a summarized version of the traditional CommonKADS (Schreiber et al., 1999) for knowledge-intensive organizations. This tool aids junior knowledge engineers in quickly understanding the organizational environment by streamlining processes and focusing solely on the context and concept levels of CommonKADS. Authors have identified redundancies in certain levels of CommonKADS, leading to consistency and integrity issues. Thus, they examined all relationships at the context and concept levels to address these challenges. The outcome was a streamlined tool, encapsulating only the essential relationships with a minimal structure and reduced processes.

Figure 2 illustrates the Lightweight CommonKADS methodology, encompassing Organizational Aspects, Business Processes, Knowledge Assets, Stakeholders, Inference, Task Method, and Information Exchange. With the assistance of this tool, the Conceptual Model for Strategic Guideline Formulation for Engineering Education was devised.

4 CONCEPTUAL MODEL

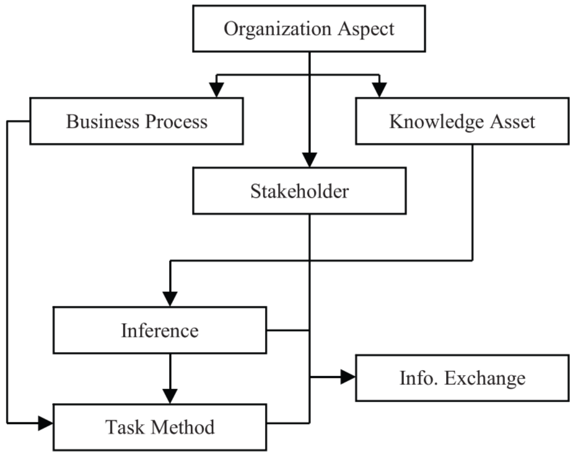
The Conceptual Model was crafted based on Lightweight CommonKADS.

4.1 ORGANIZATIONAL ASPECTS

The organizational structure, process, people, resources, knowledge, culture, and responsibilities determine the organizational aspects of the conceptual model.

The Organizational Structure has a basic framework that includes the program head, the Core Teaching Group (NDE in Portuguese), and the Council. The program head initiates the Process, which could stem from a request from the university, a change in regulation, or societal needs. The NDE then performs analyses and establishes strategic guidelines under the domain of the undergraduate engineering program. The NDE forwards these guidelines to the program head, who convenes the Council for evaluation, consideration, and approval.

Figura 2 – Lightweight CommonKADS



Fonte: Surakratanasakul (2017)

“People” refers to the internal and external stakeholders involved in devising and updating engineering programs. In the conceptual model, those directly involved in guideline formulation include the program head, NDE, and Council. Other individuals encompass staff, an accreditation team, society representatives, and students.

Resources highlight supports for academic management and those catering to Engineering Education. For the former, systems include student enrollment management, professor workload management, and Smart Learning Analytics.

Knowledge encompasses a Smart Learning Analytics system – a tool that gleans insights about students' academic performance and suggests paths to enhance learning outcomes. Competence development is deemed knowledge under faculty jurisdiction. Knowledge about engineering regulations, the minimum workload for engineering programs, and other rules fall under the purview of the program head and the NDE. Lastly, insights about society and industry are derived from reports by consultancy and research institutions and tracking alumni careers.

Culture and Responsibilities outline individual roles. The program head and NDE adapt and update the Pedagogical Program Project (PPC in Portuguese). The Council deliberates on PPC updates, while faculty are tasked with fostering student competencies.

4.2 KNOWLEDGE ASSETS

Knowledge assets arise from analyzing Regulations, Educational Technologies, and Smart Education for Engineering Education.

The program head and their NDE formulate guidelines as a task or application situation within the program head in the context of the conceptual model. The application is done correctly, assuming the formulation of guidelines comes from analyzing the regulations for Engineering Education and societal needs, as well as from Educational Technologies and best practices from Smart Education. The knowledge asset is correct if the formulation occurs in the proposed environment (in this case, the prototype implemented from the Conceptual Model).

If the guidelines are formulated at the right time, they anticipate the needs of Industry and Society and meet current legislation. Finally, the guidelines are formulated with the desired quality when the learning outcomes indicate meeting an accreditation team's goals.

4.3 TASK MODEL FOR BUSINESS PROCESSES

The task is called "Task Nx – Formulate strategic guidelines." Moreover, the organization is the Engineering Program, where the program head and NDE apply the task.

The goal of the task is "To formulate strategic guidelines for the conception (and updating) of engineering programs according to the Digital Transformation scenario." On the other hand, the value of the task was described as: "Society will count on competent engineers, that is, professionals who know how to use fundamental knowledge for certain problem situations, demonstrating professional skills, attitudes, and personal values."

Input tasks configuring dependency and flow in the Conceptual Model comprise the analysis of Engineering Education regulation, Educational Technologies, and best practices of Smart Education. Only the formulation of strategic guidelines was defined as an output task.

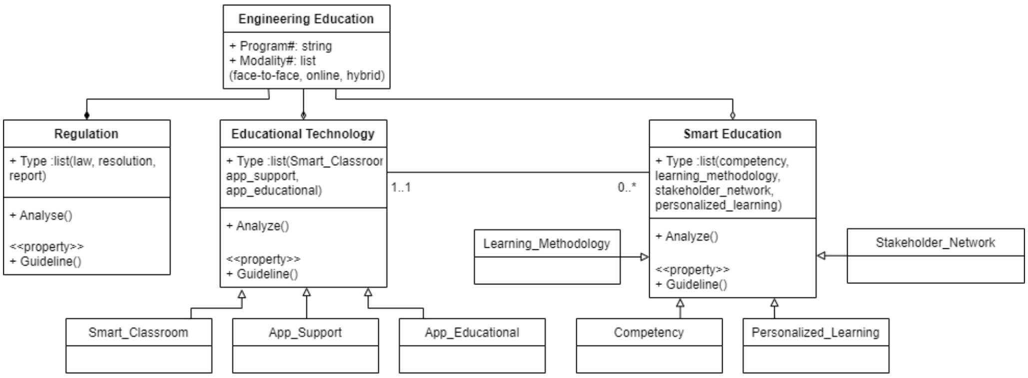
Already, the manipulated input objects are the regulation documents that affect Engineering. There are also Educational Technologies as input objects that need to be analyzed for guideline formulation; the same goes for the best practices of Smart Education. Internal objects are the internal regulations of the university, the undergraduate program, and accreditation procedures. The output objects result in the strategic guidelines. The graphic representation of manipulated objects for the Conceptual Model is illustrated in the class diagram of Figure 3. Here, a relation should be made with the Bridge from Figure 1, where Engineering Education is supported by Smart Education and Educational Technologies, with both pillars being two classes. However, there is a need to add a third class: Regulation (which affects Engineering Education).

Regarding time and control, the input tasks require varying times for the NDE, as the complexity is also variable for the input and internal objects. However, the preconditions are knowledge about the state of the art of the manipulated input and internal objects. The post-conditions are the draft of the strategic guidelines.

The agents who formalize guidelines are the program head, the NDE, and the Council. Consequently, the program head has knowledge and skills in managing people, resources, and academic planning. On the other hand, the NDE carries out educational planning, analyzes engineering education tools, proposes teaching-learning methodologies, and seeks integration of the program with Society and Industry. Finally, the council deliberates on the NDE and program head's proposals and puts the decisions into practice.

The necessary resources are information systems, hours of the program head and members of the NDE, and hours of the faculty. If the guidelines lead to results for the engineering program, quality, and performance are the performance indicators defined by the continuous improvement team linked to national and international accreditation initiatives.

Figure 3 – Class Diagram of the manipulated objects



Source: Diogo (2023)

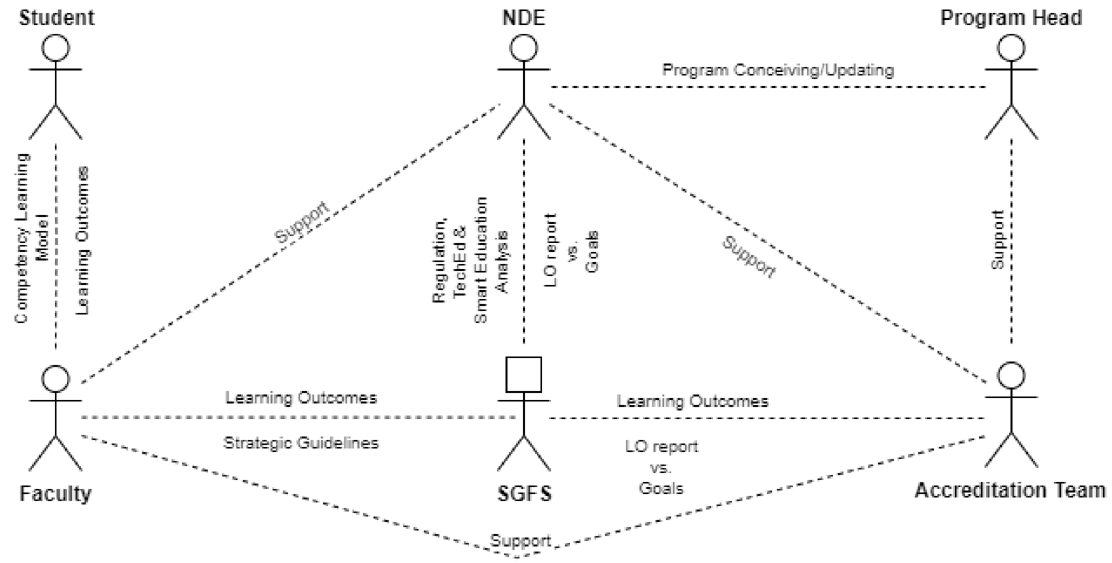
4.4 AGENT AND COMMUNICATION MODEL

Considering the "Task Nx – Formulate strategic guidelines," only the program head and the NDE apply it for guideline definition. However, the faculty must approve, making them a third interested party. One directly impacted agent is the student. Additionally, the accreditation team measures student learning outcomes (RAs in Portuguese) and issues a comparative report with established goals. Therefore, the five agents named Program Head, NDE, Faculty, Student, and Accreditation Team are in the "engineering program" organization (Figure 4). The SGFS is a System for Formulating Strategic Guidelines implemented from the Task Model, specifically from the Class Diagram and the Task Method for the Conceptual Model.

4.5 INFERENCES AND TASK METHOD FOR THE CONCEPTUAL MODEL

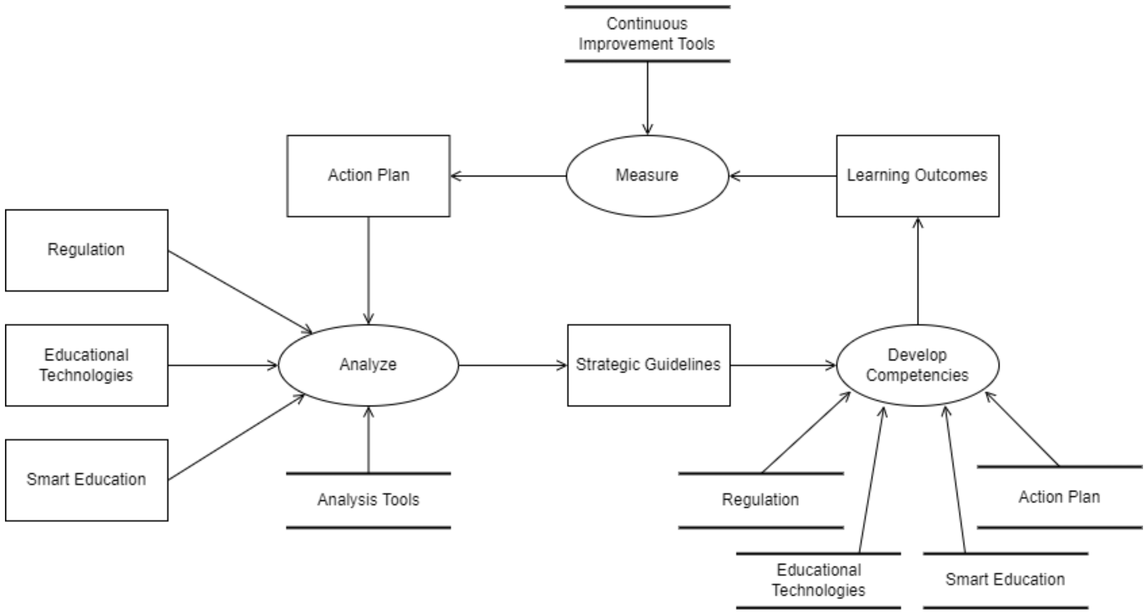
The Conceptual Model has three inferences: Analyze, Develop Competencies, and Measure. The three form the Task Method (Figure 5), which guides the work cycle in the SGFS.

Figure 4 – Communication between the agents of the "Task: define strategic guidelines."



Source: Diogo (2023)

Figure 5 – Task Method of the Conceptual Model for Formulating Strategic Guidelines



Source: Diogo (2023)

The "Analyze" inference has three dynamic input functions: Regulation, Educational Technologies, and Smart Education. This means it is necessary to analyze the input objects of these functions using the tools and analysis methods of domain knowledge. The Strategic Guidelines are formulated as a dynamic output function. However, this is the dynamic input function for the "Develop Competencies" inference.

The “Develop Competencies” inference has the “Strategic Guidelines” as its dynamic input function, producing the dynamic output function “Learning Outcomes.” This inference has four domains of knowledge. The first is about tools and examples to comply with the Regulation of Engineering Education. The second contains examples of Educational Technologies and how to use them in academic activities. The domain knowledge of Smart Education contains its best practices. Finally, the domain knowledge about “Action Plans” contains the possibilities for improving learning outcomes.

Finally, “Learning Outcomes” is a dynamic input function for the “Measure” inference. An accreditation team can carry out this inference with its methods and tools for continuous improvement, generating the dynamic output function called “Action Plans.” This ends up being the fourth dynamic input function for the “Analyze” inference. Therefore, the analysis of the action plans, combined with the analysis of the Regulation, Educational Technologies, and Smart Education, contributes to formulating strategic guidelines.

5 STRATEGIC GUIDELINES FORMULATION SYSTEM (SGFS)

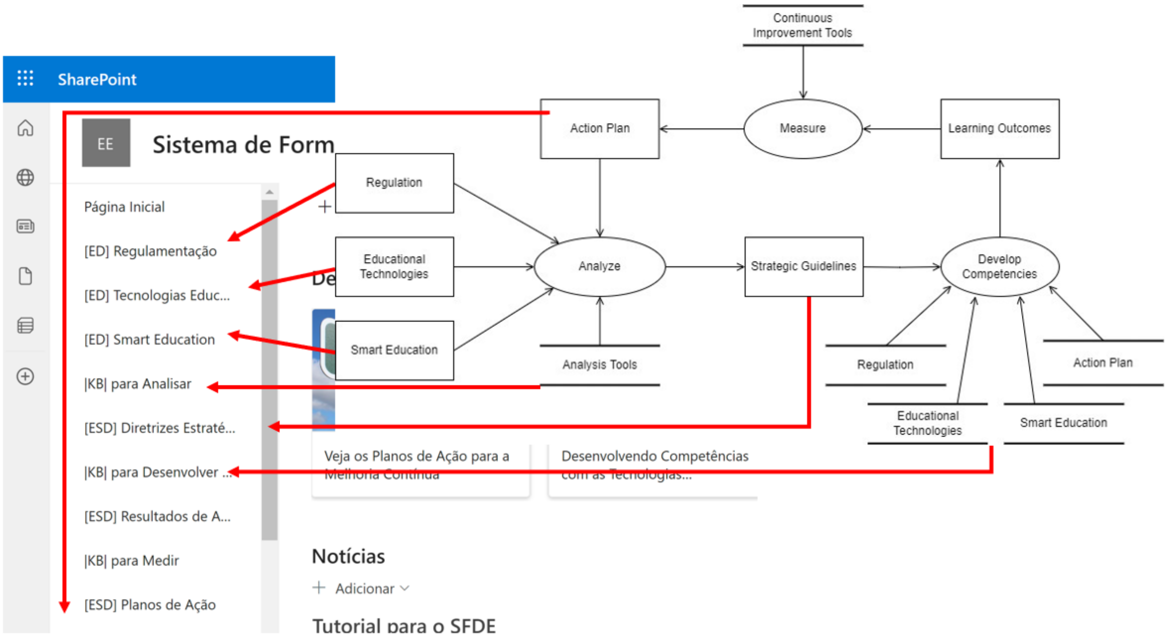
A team site was created on SharePoint to implement the SGFS. The prototype's homepage is illustrated in Figure 6. The site was reorganized with document libraries that represent, in the task method, the dynamic input functions, the dynamic output functions, and domain knowledge. The [ED] notation indicates that the document library is a dynamic input function of the task method. Whereas [ESD] is a dynamic input function for its subsequent inference, it also serves as a dynamic output function from a previous inference. Moreover, the |KB| notation signifies the domain knowledge for some inference; that is, it is a knowledge base containing consolidated tools and methods that can be used in the inferences of the task method.

The document libraries have their metadata, which, for the Conceptual Model, are the properties present in the Class Diagram of Figure 4. Therefore, properties are selected whenever an input object is manipulated in the EDs, while others are filled in, such as the Guidelines.

6 EVALUATION AND VALIDATION OF THE CONCEPTUAL MODEL

The artifact of this work is the Conceptual Model. However, experts in Engineering Education might not have adequate expertise on tools for Knowledge Engineering. Therefore, the SGFS was implemented from the design of the Conceptual Model to yield a technological artifact where the Engineering Education experts could review and provide evaluations on the prototype. Consequently, the consistency and feasibility of the Conceptual Model were evaluated, observing the model's behavior in the face of a solution to a real problem.

Figure 6 – Representation of dynamic input and output functions and domain knowledge in SGFS document libraries (SharePoint site)



Source: Diogo (2023)

The experts are representatives from 8 Brazilian universities participating in the PMG (CAPES-CNE-Comissão Fulbright, 2018), as they are professors from universities committed to modernizing Engineering Education in Brazil. The interviewees assessed the SGFS regarding functional requirements and whether it formulates strategic guidelines aligned with the needs of Digital Transformation based on the analysis of Educational Technologies, Smart Education, and Regulation for Engineering Education. The assessment also considered non-functional requirements, meaning those necessary for an artifact but not directly linked to the essential business function. For instance, structure, use, management, and environment. All requirements were assessed and validated, with minor suggestions for improvements. Therefore, the conceptual model is considered feasible and consistent.

7 DISCUSSION

The Conceptual Model is helpful as it can be implemented in any engineering program due to its replicability, provided they consider the current legislation for Engineering Education, the adoption of Educational Technologies, and Smart Education. I.e., adopting Industry 4.0

technologies and connecting with Society 5.0. This way, professionals will be competent to deal with engineering problems and challenges. Therefore, the Conceptual Model can be considered a reference for formulating strategic guidelines or an inspiration for other models.

The task method considers, in addition to the "Analyze" inference (regulation, Educational Technologies, and Smart Education), two other sequential inferences: "Develop Competencies" (from strategic guidelines) and "Measure" (learning outcomes). The task method, an integral part of the Conceptual Model, also becomes a usage suggestion. In the event of a new class diagram, there may be new dynamic input functions for the "Develop Competencies" inference and, consequently, more manipulated input objects. If this is the path, there will be a proposal to update the Conceptual Model.

The Conceptual Model design using a Knowledge Engineering tool showed that the artifact supports Knowledge Management. This is because the Conceptual Model, implemented on a computational platform, allows the analysis of existing knowledge about engineering education regulation, Educational Technologies, and the components of Smart Education. The analysis will result in formulating strategic guidelines, which are new knowledge. In this way, the Conceptual Model allows the implementation of systems for Knowledge Management, where the users are the faculty, the NDE, and the program head.

8 CONCLUSION

The Conceptual Model allows the analysis of regulatory aspects in Engineering Education to guide the NDE in formulating strategic guidelines. The model also facilitates the investigation of Educational Technologies that support the faculty in developing engineering activities for their students. Similarly, the Conceptual Model infers the analysis of components and best practices in Smart Education, including the ones that connect universities to Society and Industry, bringing real engineering problems and challenges to engineering education. The Conceptual Model allows methodologies based on active learning to be the subject of study. Therefore, faculty can lead competencies development through guidelines resulting from the analysis. However, the faculty and program head can also use Smart Education tools to support smart management. Consequently, the formulation of strategic guidelines, through the artifact, guides faculty to adopt Smart Education and Educational Technologies.

The Conceptual Model was designed with the support of Lightweight CommonKADS, proving to be a good tool for Knowledge Engineering. The methodology proved effective as a guide for learners due to the simplification of traditional CommonKADS. In the case of the

Conceptual Model, it was essential for analyzing and organizing knowledge at the context and concept level of an engineering program.

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REFERENCES

Borg, J., Scott-Young, C. M., & Turner, M. (2019). Smarter education: Leveraging stakeholder inputs to develop work ready curricula. In V. L. Uskov, R. J. Howlett, & L. C. Jain (Eds.), *Smart Innovation, Systems and Technologies* (pp. 51–61). Springer, Singapore. https://doi.org/https://doi.org/10.1007/978-981-13-8260-4_5

Brasil. (2020). Agenda brasileira para a Indústria 4.0. *Ministério Da Indústria, Comércio e Serviços*. http://www.industria40.gov.br/

CAPES-CNE-Comissão Fulbright. (2018). Programa Brasil-Estados Unidos de Modernização da Educação Superior na Graduação (PMG - EUA) - Edital no 23/2018. 1–17. https://www.capes.gov.br/images/stories/download/editais/11062018-Edital_23_PMG_EUA2.pdf

CN-DCNs. (2020). Relatório Síntese. In *Comissão Nacional para Implantação das Novas Diretrizes Curriculares Nacionais do Curso de Graduação em Engenharia* (CN-DCNs).

Contell, J. P., Díaz, O., & Venable, J. R. (2017). DScaffolding: A Tool to Support Learning and Conducting Design Science Research. In A. Maedche, J. vom Brocke, & A. Hevner (Eds.), *Designing the Digital Transformation* (pp. 441–446). Springer International Publishing.

Das, S., Kleinke, D. K., & Pistrui, D. (2020). Reimagining Engineering Education: Does Industry 4.0 Need Education 4.0? *ASEE's Virtual Conference*.

Diogo, R. A., dos Santos, N., & Loures, E. F. R. (2023). 13 - Digital Transformation of Engineering Education for Smart Education: A systematic literature review. In *M. Ram & L. Xing (Eds.), Reliability Modeling in Industry 4.0* (1st ed., pp. 407–438). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-323-99204-6.00002-9

Dneprovskaya, N. V., & Shevtsova, I. V. (2018). The Knowledge Management System Development for Smart Education. Proceedings of the 2018 International Conference "'Quality Management, Transport and Information Security, Information Technologies'", *IT and QM and IS 2018*, 602–606. https://doi.org/10.1109/ITMQIS.2018.8525129

Dresch, A., Pacheco, D. L., & Valle Antunes, J. A. (2015). Design Science Research: A Method for Science and Technology Advancement. *Springer International Publishing*. https://doi.org/10.1007/978-3-319-07374-3

Fisk, P. (2017). Education 4.0 … the future of learning will be dramatically different, in school and throughout life. https://www.peterfisk.com/2017/01/future-education-young-everyone-taught-together/

Frank, A. G., Ayala, N. F., Benitez, G. B., Marcon, É., & Lerman, L. V. (2021). Profissões Emergentes na Era Digital: Oportunidades e desafios na qualificação profissional para uma recuperação verde - Panorama do Brasil. https://www.portaldaindustria.com.br/publicacoes/2021/7/profissoes-emergentes-na-era-digital-oportunidades-e-desafios-na-qualificacao-profissional-para-uma-recuperacao-verde/

Graham, R. (2018). The global state of the art in engineering education. https://jwel.mit.edu/assets/document/global-state-art-engineering-education

Makarova, I., Shubenkova, K., & Antov, D. (2019). Digitalization of Engineering Education: From E-Learning to Smart Education. In *M. E. Auer & R. Langmann (Eds.), Smart Industry & Smart Education* (pp. 32–41). Springer, Cham. https://doi.org/https://doi.org/10.1007/978-3-319-95678-7_4

MEC, & INEP. (2021). Censo da Educação Básica 2020 - Resumo Técnico. In *Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira*. https://download.inep.gov.br/publicacoes/institucionais/estatisticas_e_indicadores/resumo_tecnico_censo_escolar_2020.pdf

OECD. (2019). OECD Learning Compass 2030: A Series of Concept Notes. In *OECD Future of Education and Skills 2030*. OECD. https://www.oecd.org/education/2030-project/

OECD. (2021). Education in Brazil. https://doi.org/https://doi.org/https://doi.org/10.1787/60a667f7-en

Oliveira, V. F. de. (2019). A Engenharia e as Novas DCNs: Oportunidades para Formar Mais e Melhores Engenheiros (LTC, Ed.; 1st ed.). Grupo GEN.

Schreiber, G., Akkermans, H., Anjewierden, A., de Hoog, R., Shadbolt, N., Van de Velde, W., & Wielinga, B. (1999). Knowledge Engineering And Management: The CommonKADS Methodology. *The MIT Press*. http://books.google.pt/books?id=wY9EylLwBPEC

Shafeek, H. (2019). Applying Lean Concepts in the Quality Control Systems of Engineering Education - A Case Study. *2019 Industrial and Systems Engineering Conference, ISEC 2019*. https://doi.org/10.1109/IASEC.2019.8686676

Surakratanasakul, B. (2017). Lightweight CommonKADS in knowledge intensive organization. *2017 9th International Conference on Information Technology and Electrical Engineering, ICITEE 2017*, 2018-Janua, 1–5. https://doi.org/10.1109/ICITEED.2017.8250504

Tikhomirov, V., Dneprovskaya, N., & Yankovskaya, E. (2015). Three Dimensions of Smart Education. In *V. L. Uskov, R. J. Howlett, & L. C. Jain (Eds.), Smart Education and Smart e-Learning* (pp. 47–56). Springer International Publishing.

Uskov, V. L., Bakken, J. P., Shah, A., Krock, T., Uskov, A., Syamala, J., & Rachakonda, R. (2019). Smart learning analytics: Conceptual modeling and agile engineering. *Smart Innovation, Systems and Technologies*, 99, 3–16. https://doi.org/10.1007/978-3-319-92363-5_1

World Economic Forum. (2021). Building a Common Language for Skills at Work: A Global Taxonomy (Issue January).

World Economic Forum. (2023). Defining Education 4.0: A Taxonomy for the Future of Learning (Issue January).