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Skills for Prospective Civil Engineers: Mastery of Current and Future Situations

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Abstract: This study aims to explore the competency mastery of prospective civil engineers based on the 3rd edition of the Civil Engineering Body of Knowledge and predict the future skills needed for prospective civil engineers in the next 10-20 years. A quantitative approach with a survey method was carried out to answer the first research objective. The questionnaire is filled out by prospective civil engineers who are final-year students of bachelor's in civil engineering. Next, a descriptive analysis was conducted to provide an overview of the mastery of competencies. Finally, the Systematic Literature Review (SLR) method was carried out to answer the second research objective. The analyzed literature uses the Scopus Database with keywords that describe future work skills and competencies. Then the articles were then filtered using the PRISMA Diagram and analyzed with the help of the R program to produce a word cloud that describes the types of future skills needed. The research results show that 1) civil engineer candidates must increase competence in the application of natural sciences, humanities aspects for Civil Engineering, mechanics and fluids problems, formulation of solutions to problems relevant to Civil Engineering, engineering economics, probability concepts, and statistics. 2) They must develop future skills needed for prospective civil engineers: critical thinking, communication, professionalism, problem-solving, leadership, teamwork, collaboration, and the principle of sustainability. The findings of this study serve as evaluation material and recommendations for civil engineering education providers to prepare prospective civil engineers with a global outlook.

Keywords: civil engineers, prospective civil engineers, future skills, job competencies, skills forecasts.

土木工程师候选人的技能：掌握当前和未来的情况

摘要:

本研究旨在基于第3版土木工程知识体系探索准土木工程师的能力掌握情况，并预测未来10-20年准土木工程师所需的未来技能。为了回答第一个研究目标，采用了一种带有调查方法的定量方法。调查问卷由未来的土木工程师填写，他们是土木工程学士学位的最后一年学生。接下来，进行了描述性分析，以提供对能力掌握情况的概述。最后，采用系统文献综述（单反）方法来回答第二个研究目标。所分析的文献使用带有描述未来工作技能和能力的关键字

的斯科普斯数据库。然后使用棱镜图对文章进行过滤，并在R程序的帮助下进行分析，以生成描述未来所需技能类型的词云。研究结果表明，1)
土木工程师候选人必须提高在自然科学、土木工程人文学科、力学和流体问题、土木工程相关问题解决方案的制定、工程经济学、概率概念和统计学方面的应用能力。2)
他们必须培养未来土木工程师所需的未来技能：批判性思维、沟通、专业、解决问题、领导能力、团队合作、协作和可持续性原则。本研究的结果可作为评估材料和建议，供土木工程教育提供者培养具有全球视野的未来土木工程师。

关键词：土木工程师、未来的土木工程师、未来技能、工作能力、技能预测.

1. Introduction

Civil Engineering was defined in the 18th century by Thomas Tredgold in 1828, namely, "the art of directing the great sources of power in nature for the use and convenience of man" [1]. For nearly two centuries, the science of Civil Engineering still exists and has been developed. In the era of the Civil Engineering Industrial Revolution 4.0, in this case, the construction industry adapted very quickly. It is evidenced by the existence of "Construction 4.0", a terminology that embraces four main concepts: digital data, automation, connectivity, and digital access. "Construction 4.0" is defined in [2] as the transformation of the construction company of project management processes through the use and exploitation of data collected in real-time using new or existing technologies for decision-making purposes.

Increasing new technology used for work productivity is one of the challenges of industrial transition in the 21st century [3]. In Civil Engineering, the basic drawing skills required by drafters will become obsolete skills that are no longer needed because they are replaced by Building Information Modeling (BIM). However, learning in tertiary institutions, especially in developing countries, still applies traditional learning. However, the curriculum has yet to be designed based on future needs [4]. Therefore, current Technical and Vocational Education and Training (TVET) practitioners must model the future skills required in each sector. One industry that requires a large number of workers is civil engineering. It is needed not only by Civil Engineering academics who focus on innovative research in nanomaterials, digital construction technology, or smart homes. Rather, social researchers and TVET practitioners will develop a curriculum for the Civil Engineering program based on future needs in the next 20-30 years through futuristic studies. A futuristic study, in this case, is job competence forecasting.

Thus, competency analysis in the world of construction work has focused on one skill, such as management skills [5], critical and mathematical thinking skills [6], communication [7], and leadership [8]. Additionally, the identification of skill attributes has also been developed and researched in several countries, such as Indonesia [9], Malaysia [10], India [11], dan USA [12], with different measurement standards. This research uses two different research approaches and will answer 1) What are the competencies that prospective civil engineers do not yet master at this time? and 2) What are the future work competencies required by prospective Civil engineers? The first question is a form of mapping the mastery of competence for prospective civil engineers. Civil Engineering Body of Knowledge edition 3 (CEBOK3) [13] is used as a reference for the questionnaire distributed to bachelor students of Civil Engineering in Indonesia. The second question with the Systematic Review method will strictly collect research on Civil Engineering work competencies. It is a form of effort to predict the work competencies needed for future civil engineer candidates. Including answering what types of skills are focused on by TVET academics and practitioners so that they can be immediately taught and trained to Civil Engineering students globally.

2. Method

The existing two research methods can answer these two research questions. The first method is a survey to answer the question, "What are the competencies that prospective civil engineers have not mastered at this time? The second method is a Systematic Review to answer the "What are the future job competencies required for prospective Civil Engineers?" In the first method, questionnaires were sent to final-year students of Civil Engineering from Jakarta State University, Yogyakarta State University, Ambon State Polytechnic, and Malang State Polytechnic. Four universities were chosen because they were considered to represent civil engineering students in West Indonesia and East Indonesia. The choice of these four universities is a limitation of this research, considering that the number of universities in Indonesia is very large. Table 1 shows that the population of final-year

civil engineering students was 240, and 186 have filled out the survey. This means that 77.5% of respondents represented the population.

Table 1 Research respondents

University	Final-year students	Respondents
Jakarta State University	50	37
Yogyakarta State University	83	63
Ambon Sate Polytechnic	47	36
Malang State Polytechnic	60	50
Total	240	186

Questionnaires were sent via online media, such as WhatsApp, email, and Instagram. The questionnaire consisted of two parts. The first part contains questions about the origin of the college, the program of study, and the year of entry. The second part is the main part of the questionnaire, which contains 27 statements regarding the competence of Civil engineers based on the Civil Engineering Body of Knowledge edition 3 (CEBOK3) standard [5]. In addition, descriptive statistics are used as data analysis to show the mastery of each competency.

In the second method, the article collection uses the software "Publih or Perish (PoP)" https://harzing.com/resources/publish-or-perish and "Watase Uake (WU)" http://watase.web.id/ with the Scopus database. The difference between the two software is in the search process. PoP combines two words as terminology. As for WU, each word is a different terminology. Some keywords used include: [civil engineer, future skills], [civil engineering, new skills], [civil engineer, future studies], and [foresight, civil engineer]. Furthermore, the article selection rules adopt the PRISMA method [14], which consists of identification, screening, eligibility, and inclusion. More clearly can be seen in Figure 1.

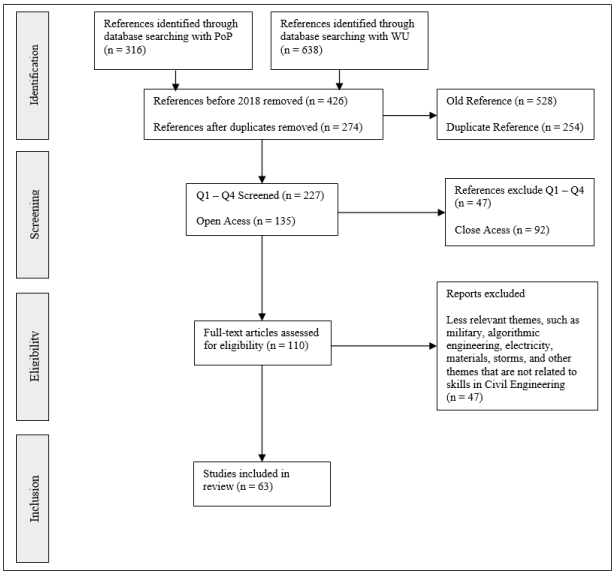

Fig. 1 PRISMA diagram [14] used in systematic literature review

In the final stage, 63 articles were reviewed. Each article will identify the skills and keywords needed for civil engineers in the future. These keywords are stored in a .TXT file then, with the help of R software, an analysis is made in the form of a word cloud. A word cloud can help quickly and efficiently analyze and research text so that readers understand the meaning more quickly [15]. Here, the word cloud will analyze the trend of researchers in viewing work competencies and future skills needed for prospective civil engineers.

3. Results and Discussion

3.1. Mastery of Current Prospective Civil Engineers' Competencies

Civil engineer candidates have at least mastered the minimum competencies regulated by [13]. Based on CEBOK3, there are four outcome categories: foundational, engineering fundamentals, technical, and professional. Foundational provides the knowledge bases for other competencies, which are general, not only specifically for civil engineers. Engineering fundamentals as a liaison between foundational and technical. Engineering disciplines have such characteristics. Technical is a specialty for civil engineering, while professionals are related to soft skills that focus on interpersonal and intrapersonal [13].

3.1.1. Foundational Skills

Foundational skills are one of the future skills that are the focus of the UNICEF Global Framework reported. Basic skills can be said as skills that must be mastered when someone undergoes elementary school education, maybe even before. Here, the foundational skills consist of Mathematics, Natural Sciences, Social Sciences, and Humanities.

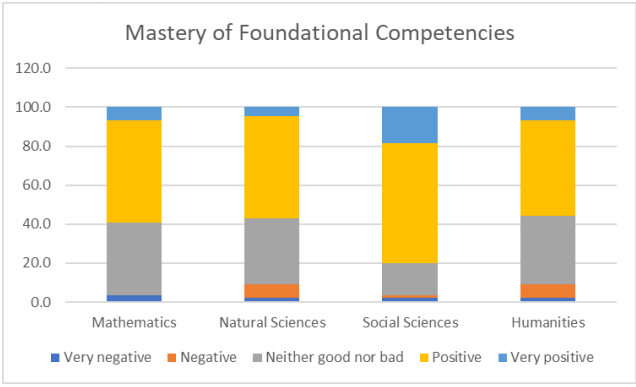

Fig. 2 Mastery of foundational competence for prospective civil engineer

Based on Fig. 2, natural science and humanities have a negative value. This means that prospective civil engineers feel that they have not mastered these two competencies. Natural sciences consist of several scientific disciplines, but [13] explains that physics and chemistry are two natural science disciplines that are the basic foundation of Civil Engineering science. Phenomena that occur in construction material

problems will find a solution with chemistry. Physics is widely relied upon in the field of civil engineering because of its characteristics of having accurate instrumentation and measurement precision. Therefore, in this case, calculus-based physics is applied to solve engineering problems [13].

Humanities is often combined with Social Sciences to become Social Sciences and Humanities (SSH). In this case [13] explains that Humanities include philosophy, story, literature, visual and performing arts, language, and religion. However, the social sciences study humans, how people behave, and their influence on the environment around them. SSH generally enables civil engineers to make more responsive, realistic, and critical decisions about existing social phenomena. SSH is a heterogeneous set of scientific disciplines that helps provide answers by reflecting the dimensions of society and human behavior. SSH will direct Civil engineers to plan and design solutions based on socially sustainable principles [16].

Based on Fig. 2, Mathematics is the most trusted competency mastered by prospective civil engineers. Mathematics is a competency that civil engineers must master because every engineering construction is calculated mathematically. This competency is the basis and determinant of success in studying at the Faculty of Civil Engineering. The mastery of mathematical knowledge impacts successful graduation at the Faculty of Civil Engineering. The core of the Mathematical materials in Civil Engineering is matrices, limits, derivatives, integrals, and their application in civil engineering [17]. More fully [13] explains that Mathematics material related to Civil Engineering, namely: algebra, calculus, linear algebra, geometry and topology, differential equations, computation and numerical analysis, probability, set theory, statistics, and trigonometry. [18] even gave examples of the application of mathematics for civil engineers, such as load calculations, structural stability, material selection, design of engineering systems, and infrastructure.

3.1.2. Engineering Fundamentals

Engineering fundamentals are the foundation for students to understand the basics and certain design variables. It includes one of the competency sections taught to Civil Engineering students in the first and second years. The successful engineers have a good understanding of the Engineering Fundamentals, which they later used to understand and solve different problems, regardless of specialization. Here, engineering fundamentals consist of material sciences, engineering mechanics, experiment method and data analysis, and critical thinking and problem-solving.

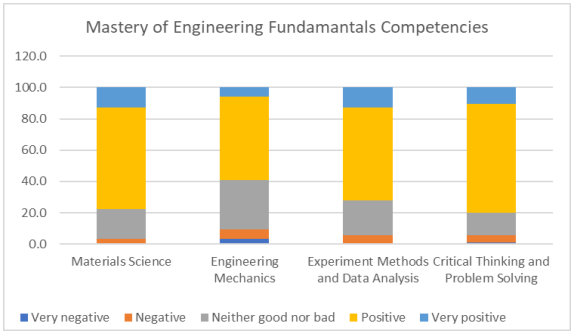

Fig. 3 Mastery of engineering fundamentals competency for prospective civil engineer

Of the four competencies included in engineering fundamentals, Critical Thinking and Problem Solving and Materials Science showed very positive values compared to the other two competencies. This shows that prospective civil engineers feel they have mastered these two competencies. According to [19], in general, critical thinking is considered the main goal of higher education and becomes one of the important skills within the scope of engineering education. Critical thinking and problem-solving are inseparable parts of one skill. Problem-solving skills in the construction industry have a fairly broad impact on the success of projects and careers of Civil engineers, as for material science in the context of civil engineering, such as concrete, steel, wood, asphalt, glass, fiber, water, rock, and soil, and its development. Prospective civil engineers should understand the properties and behavior of these materials for selecting material types and for making appropriate specifications for their use [13].

Engineering mechanics has a greater negative value than other competencies. This means that prospective Civil Engineers need more confidence in mastering this material even though they assess the importance of mastering Engineering Mechanics. It is necessary to reform learning in the Mechanical Mechanics course [20] so that students learn to relate mechanics concepts to problems in the real construction world. Another indicator is the experimental method and Data Analysis. For final-year students, most of the capstone projects they do will be related to this competency. This competency is difficult to master because experimentation is a work procedure to discover or determine something that was not known. These competencies are integrated with basic knowledge such as mathematics and natural sciences. As stated in [21], the basic concepts studied in materials mechanics and materials science are prerequisites for various higher-level courses, such as structural analysis and design of various structural elements.

3.1.3. Technical Competencies

Technical competencies are specific. This competency is used to conduct certain tasks in one's job or profession. [22] explains that technical competence means the practical skills needed in the

technology sector. In this case, technical competence consists of several indicators: project management, engineering economics, risk and uncertainty, breadth in Civil Engineering areas, design, depth in the civil engineering area, and sustainability.

Based on Fig. 4, it can be concluded that engineering economics, risk, and uncertainty are the indicators that have the most negative values. Civil engineering candidates consider that they have not mastered engineering economics, risk, and uncertainty. [23] explains that studying Engineering Economics will equip novice engineers with the tools of Economic analysis and more rational decision-making.

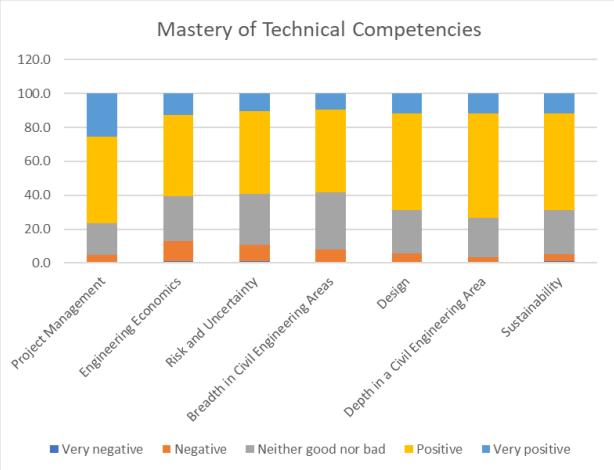

Fig. 4 Mastery of technical competence for prospective civil engineer

The combination of engineering and economics is an important part of the success of engineers in the 21st century. Indicators of risk and uncertainty are related to the principles of probability and statistics. This capability needs to be implemented to minimize risks to the project [13]. It is possible that engineering students think that studying statistics and probability is useless, difficult, and boring. This factor causes this indicator to be perceived as needing to be mastered by prospective civil engineers.

Furthermore, of the seven indicators of technical competence, project management has a greater positive value than other indicators. This means that project management and depth in a civil engineering area for prospective civil engineers are considered to have been mastered by them. Learning innovation in the project management course plays an important role. Several learning innovations have been carried out to improve student skills in project management courses, such as the poll app, active learning, and using software.

Breadth in civil engineering areas [13] states that at least prospective civil engineers must master the application of 4 special fields relevant to civil engineering to solve complex problems. Examples of construction, environmental, geotechnical, and structural engineering may be more than mentioned. The depth of the civil engineering area involves a deeper understanding or specialization in fields relevant to civil engineering. With this ability, a civil engineer will be known as an "expert." In design indicators, of course, this is one of the characteristics of civil engineering. In general, civil engineering designs are 2D drawings and 3D model designs. Designs and drawings are important for communicating engineering ideas to stakeholders so they can convey visual instructions on how to build, view, and design philosophy. The last indicator represents the capabilities needed to face the future, namely, sustainability. The civil engineer candidates' abilities are average. It can mean that some students understand, but others do not. The principle of sustainability to balance economic, ecological, and community needs responsively to the impacts of society, human health, and the environment. In other words, sustainable development expects resilient infrastructure to last, maintain functional and structural capacity, and support-interconnected transportation, energy, water, and social systems. In the future, there are more and more problems facing engineers related to the environment and ecology, which are increasingly fragile. Civil engineers, as policymakers, should design solutions and consider the impact of their decisions on citizens.

3.1.4. Professional Skills

Professionalism can be interpreted as a person's capability to conduct his profession and work. Professional as a highly qualified individual who has undergone significant education and training. Here, professionals consist of: communications, teamwork and leadership, lifelong learning, professional attitudes, professional responsibilities, and ethical responsibilities.

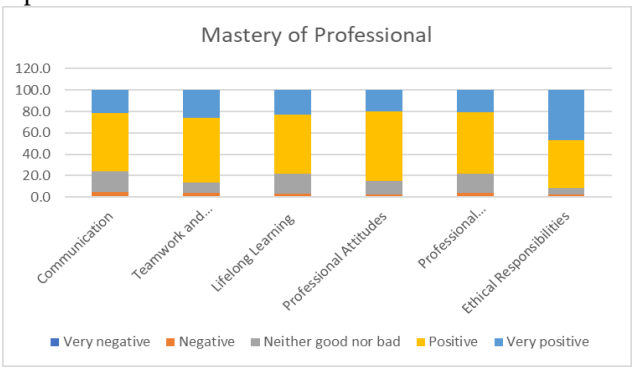

Fig. 5 Professional mastery of prospective civil engineer

Although not too significant, the communication indicator has a greater negative value than the other indicators. Therefore, the communication skills of prospective Civil Engineers need to be improved, especially communication in foreign languages. The knowledge of the English language, and communication skills, are complex problems for Civil engineering students, especially those from rural areas. However, according to [24], the ability of graduates to communicate effectively can significantly impact the career development of Civil Engineering graduates. Therefore, providing future engineers with an

appropriate language learning environment is the best option to prepare aspiring civil engineers to face the challenges of communication as professionals [25].

Ethical responsibility is one of the six indicators with the greatest positive value. This means that prospective civil engineers believe that they have been able to implement ethical responsibilities. Ethical responsibilities relate to the responsibility of civil engineers to show honesty, integrity, and fairness and be aware of conflicts of interest [13]. In other words, on this indicator, civil engineers are expected to be able to behave according to the applicable code of ethics. Engineers' Code of Ethics is a guideline for how an engineer should behave professionally. Furthermore, ethics and morals must be maintained and discussed throughout the undergraduate education process to make students more likely to practice ethical behavior after graduation [26]. Therefore, universities need to associate student activities oriented toward the application of ethical behavior with professional responsibilities related to legal issues and licenses, including relevant regulations, standards, codes, contracts, and guidelines [13]. The difference is the guidelines used in applying responsibility.

Other indicators, such as teamwork and leadership, life-long learning, and professional attitudes, are, on average, at the level of being mastered by prospective civil engineers. However, the application of these values is more difficult than written recognition. Therefore, the curriculum in engineering education must provide opportunities for activities that create a collaborative environment and leadership development in line with industry and professional expectations. Likewise, with indicators of life-long learning (LLL). This represents the notion that learning must occur at all life stages. For engineering students, LLL is the ability to continue learning and add to their skills. Finally, professional attitudes relate to the positive and constructive attitude that must be shown by a civil engineer, which includes creativity, curiosity, flexibility, and dependability [13]. There are strong reasons to consider the need for future engineers to develop their professional activities with the requisite responsibility and ethics. It is even said that the civil engineering profession is founded on a moral imperative to serve and benefit society [27].

Based on the results of the analysis in each of the four competency categories, it is known that the mastery of competencies that most needs improvement is in: the application of natural sciences, humanities aspects to problems in Civil Engineering, mechanics and fluids, formulating solutions to problems relevant to Civil Engineering, engineering economics, as well as the concepts of probability and statistics. In other words, maximum effort is needed to overcome this gap so that in the future, civil engineer candidates can apply the knowledge, attitudes, and skills mastered to solve complex problems.

3.2. Necessary Future Skills for Civil Engineers

The skills needed for Civil Engineering graduates are described in [28], namely: technical knowledge, professional skills, material testing skills, the ability to perform experiments and drafting and plotting skills, practice ethics and exhibit professional skills such as communication, teamwork, leadership, and critical thinking. However, in this study, future skills emerged from a systematic literature review with word cloud analysis. The results showed three skill categories based on the colors that appeared in the word cloud. The first category is purple: work, thinking, communication, and professionalism. The second category is brown: technical, problem-solving, leadership, design, and teamwork. Finally, the third category is green, namely: collaboration and sustainability.

Fig. 6 Word cloud analysis of future skills for civil engineers

The first category can be said as basic skills in work, namely: work, critical thinking, communication, and professionalism. It is general, not just civil engineers. Concerning work skills, civil engineers work in a field or industry that has risks of work accidents [29]. Therefore, it is important to master hazard-recognition skills for aspiring civil engineers. Risk management, particularly the management of natural hazards and territorial risks, has become an important skill for civil engineers [30]. Next is thinking skills. Critical thinking and mathematical thinking are closely related and indispensable in solving complex engineering problems, including civil engineering [31]. Thinking skills in civil engineering, critical and mathematical, are often referred to as design thinking [32] and higher-order thinking [33]. Including communication and professional competence. Thus far, ineffective communication between engineers and contractors is a cause of obstacles to the success of civil engineering projects [34]. Therefore, in the future, prospective civil engineers need to practice communication skills as a provision for them in the future workplaces [24], including the mastery of

foreign languages. Future civil engineers will work in a highly multicultural and multinational environment [28]. Along with this, the manager of the Civil Engineering study program should prepare graduates with professional skills to compete in the world of the work market.

The second category is closer to the specific skills that civil engineers need to master: technical, problem-solving, leadership, design, and teamwork. In [13], it is stated that technical competence consists of several indicators: project management, engineering economics, risk and uncertainty, breadth in Civil Engineering areas, design, depth in the civil engineering area, and sustainability. Three themes of critical technical skills are required for IR4.0: analyzing, interpreting, and documenting data; understanding and optimizing processes; and, execute, troubleshoot, and maintain devices [35]. In the future, the technical requirements may change. However, competencies in the form of good values will still be needed. Some researchers mention them as transversal skills [36], such as 1) problem-solving skills, which are mentioned by [37] as essential skills in technical education. 2) leadership. [38] mentions that leadership is the most important skill since the Industrial Revolution 4.0 era. 3) teamwork. The curriculum in civil engineering education should organize learning that provides opportunities for students to work in teams. Another skill is design, the rapid growth of BIM technology, 3D modeling has become an important skill for civil engineers. [39] adds the necessary skills for Civil engineers to face future challenges, namely, the skills of designing modern structures.

The third category is closely related to skills that are predicted to be needed to face the future in 10-20 years: collaboration and sustainability. The development of the city of the future requires Civil engineers who have a vision for the future, apply sustainable, intelligent and adaptable concepts and collaborate with all professional fields and policymakers. Collaboration between scientific and professional fields shows the scientific interdisciplinary that civil engineers will face in the world of work. This type of skill needs to be prepared by emphasizing transferrable engineering skills and knowledge [40]. In addition, the paradigm of sustainable development (sustainability) must be instilled in lectures to prepare civil engineers who can implement innovative solutions and minimize environmental impacts amidst a growing population [41]. Civil Engineering is the foundation of a scientific discipline that provides students with knowledge and skills regarding sustainability. As stated in [42], civil engineers are expected to impact sustainable development. Therefore, Civil Engineering students need learning materials that support developing sustainable design skills.

The categorization of the results of this study confirms some of the results of previous studies, which state that the main requirement for successful development is a competent construction workforce with much expertise [43]. Other studies have examined eight skills required for civil engineering graduates based on a professional perspective: managerial skills, site administration skills, business development skills, design management skills, procurement and materials management, risk management skills, planning and scheduling, ethics, and professionalism [11]. Verification results on the generic skills of the Industrial Revolution 4.0 needed for novice civil engineers: communication, problem-solving, leadership, emotional intelligence, creativity, critical thinking, adaptability, digital, and management skills [10]. Other explorations viewed from the perspective of Civil Engineering practitioners and academics obtained ten competencies [9], namely: interpersonal management skills, personality traits, entrepreneurial and business skills, knowledge of digital technology, team playing, civil engineering skills technical, geotechnical knowledge, communication skills, client orientation skills, and mentally strong and positive attitude.

Even the future, filled with volatility, uncertainty, complexity, and ambiguity (VUCA), requires earlier anticipation, namely forecasting skills. The results of this study as a form of effort forecasting skills. Forecasting skills in the construction sector will provide information on future skills for workers, educators, students, curriculum developers, and policymakers in the construction services sector. Skill forecasting will respond to organizational needs and contribute effectively to the transformation of society through the practical business/business they run [44]. Besides that, forecasting future skills will provide insight to education policymakers and curriculum developers about appropriate interventions to equip graduates with the job skills needed in the future.

4. Conclusion

The results of the study show that prospective civil engineers have not mastered several basic competencies as foundational skills for future civil engineers, including several competencies that are fundamental and technical. In basic competence, prospective civil engineers have not mastered natural sciences and humanities. Regarding essential engineering competencies, the Engineering Mechanics course is a particular problem for future civil engineers. Technical competencies that need to be mastered are financial engineering and risk and uncertainty, in this case, concerning statistics and probability. Finally, in professional competence, communication is an indicator that needs to be improved compared to other hands. Based on the results of a literature review on future skills for prospective civil engineers, three categories of skills were obtained, namely: 1) basic skills for work; 2) special skills for prospective civil

engineers; and 3) skills needed.

This study performed two activities: identifying competency mastery and predicting future skills, whereas previous studies carried out these two activities separately. The results of this study are more general for prospective civil engineers compared to [43], identifying in detail the key future skills required by ten types of civil engineering professions, including at the operator level. The use of CEBOK 3 as the main guide is seen as a wise move and is more global than some studies reliant on the perspectives of local practitioners. Therefore, using the two methods and CEBOK 3 is the research strength.

The research results have implications for administrators and lecturers in the civil engineering study program to better prepare their students as prospective civil engineers who are competent in technical matters; these competencies come from a deep understanding of scientific philosophy and can apply future skills to prospective civil engineers who are insightful global. The limited number of respondents is a limitation in this research, so the results of this study should reflect the mastery of competence of most prospective civil engineers. However, four universities are considered sufficient to represent many universities in Indonesia.

Future research should identify competency mastery for prospective civil engineers with a more significant number of respondents. Additionally, cooperation with futurists is deemed necessary to strengthen the results of forecasting skills for the future.

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