Computers in Industry

Toward a Sustainable Engineer Archetype through Industry 4.0

--Manuscript Draft--

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Abstract:	In the last decade, a shift toward Sustainable Development (SD) in engineering has started in the educational and occupational framework. Therefore, the need to rethink the professional figures of an engineer has become a necessity. Unfortunately, neither a formal methodology to define a standard engineer archetype nor procedural methods to evaluate such archetypes' contribution to SD are investigated. This paper bridges the first gap by proposing a general methodology to define specific engineer archetypes as technical competences from educational - Semi Structured Intended Learning Outcomes (SS-ILOs) - and occupational - European Skills, Competences, Qualifications and Occupations (ESCO)- frameworks. The second gap is addressed by a procedural method based on indirect mapping of the identified archetypes onto United Nations Sustainable Development Goals (UN-SDGs). Since Industry 4.0 (I4.0) is related to engineer archetypes and SDGs, it is used as a bridge. Finally, we provide the application of our proposed methodology to the Industrial engineering case study. The results show that significant limitations toward sustainability remain open challenges. However, the intrinsic nature of the industrial engineer is confined to some specific goals, and a characteristic signature on sustainability emerged.
Response to Reviewers:	

Response to the comments about the submitted paper COMIND-D-21-00710

Title [NEW]: Toward a Sustainable Engineer Archetype through Industry 4.0

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In this document, we provide our answers to the reviewers' comments.
A version of the revised paper with all the modifications highlighted (track changes mode) is also provided.

Reviewer 1

Comment	**Answer**
Good paper on a very current and important topic.	Before we illustrate our updates, we would like to thank Reviewer 1 for his time and effort in evaluating our article and providing his valuable comments and appreciation.
The presentation is good, but without reading the relevant preparatory work, the methodology is hard to follow. You assume a lot of prior knowledge about your work from the readers. A more low-level and small-step presentation would support the strength of the content of the article.	We report a summary of the main changes we have carried out in the interest of your comments (as anticipated, all the modifications are highlighted in a separate version of the revised paper using .docx "track changes mode"): -**Title** keywords (here in *italic*) of the revised paper are now arranged to highlight *Industry 4.0* as an enabler for defining *engineer archetypes* (RQ1) and evaluating its contribution to *sustainability* (RQ2). -The **Abstract** of the revised paper has been improved. **-Section 1 "Introduction"** of the revised paper has been modified by clearly declaring the research gap, the motivation, the contribution and introducing the methodology step by step. **-Section 2 "Background"** presents new and more recent references. The additional **section 2.5 "Industry 4.0 (I4.0) and Sustainable Development (SD)"**, has been added to provide adequate background. A direct linkage to the new

	output Table 4 synthesising the impact of the 44 technology elements on the 17 SDGs is provided in the revised **Appendix 1 "*Industrial* engineer A, B and C matrices"**. **Section 3 "Methodology"** in the revised manuscript now details the description of the methodology step-by-step and integrates a significant amount of new information. **-Section 4 "*Industrial* engineer archetype case study"** in the revised manuscript now provides the following information for the *industrial* engineering case study: a sample of courses considered; two examples of the SS-ILOs defined as well as examples of the selected ESCO competences. Less relevant discussions have been moved from **section 4.3 "Interpretation of *Industrial* engineer archetype contribution to Sustainable Development (SD)"** to the new **Appendix 2 "Detailed discussion on the *Industrial* engineer archetype contribution to SD"** to improve readability. **-Section 5 "Discussion".** The primary use of the two results of the *industrial* engineer archetype and its contribution to Sustainable Development (SD) are reported at the beginning of the revised section. Additional future work and issues have been included. **-Appendix 1 "*Industrial* engineer A, B and C matrices"** in the revised manuscript contains the three matrices on which the paper is based. **-Appendix 2 "Detailed discussion on the *Industrial* engineer archetype contribution to SD"** in the revised manuscript is a detailed discussion of the *industrial* engineer archetype contribution to Sustainable Development (SD). **Other**: The terminology has been uninformed throughout the manuscript to improve consistency. A total of 27 new references have been added. English have checked and grammatical errors addressed.

Reviewer 2

Comment	*Answer*
The topics you address in the manuscript, i.e. sustainable development (SD), Industry 4.0 (I4.0), and competence requirements, are important and in need of further research. The basic idea, to understand the cross-section of these topics, is novel. However, there are some major drawbacks with the current manuscript that have to be addressed. Please find my comments and reflections below. Issues with problem formulation, relevance and implications	Before we illustrate our updates, we would like to thank Reviewer 2 for his time and effort spent evaluating our article and providing detailed comments and appreciation.
The main results are an approach for defining engineering archetypes and the engineering archetype assessed for its sustainability. These corresponds well with the research questions.	Thank you for highlighting this contribution of our paper.
It is not obvious 1) *who* would benefit in developing such archetypes, and for *what* purpose? 2) *Why* is it important to define archetypes? 3) and *what* are the benefits in connecting these with I4.0 and SD?	1) Thank you for pointing this out. in the revised **section 1 "Introduction"** it is stated, among other, four clear benefits (i.e., evaluation, design, comparison, and communication) for stakeholders in the educational (e.g., students, professors, universities as institutions) and occupational (e.g., placement services, private companies, public bodies) framework. We also highlight that using actual syllabi from education programs and occupational information, in contrast to regulatory documents, is a specific representation of a particular class of engineers based on existing implementations. 2) Please see the answer above. 3) The reason for connecting engineer archetype to I4.0 and I4.0 to SD was also introduced in **section 1 "Introduction"**. Summarizing, the benefit of connecting I4.0 to the engineer archetype and SD is the possibility to map how much a specific engineer archetype contributes to SD (using I4.0 as a "bridge"). Moreover, we also highlighted how, despite several methodologies on quantitative assessment of I4.0 technologies have been developed, and rather significant literature on the sustainability assessment in the educational framework is available, a general methodology for the assessment of engineer

	contribution to SD still lacks.
Moreover, the motivation and relevance should be built on *references*. Right now, it is only stated in the introduction that "Unfortunately, we are not aware of a methodology…". From the descriptions, it is not fully clear what an "archetype" is either, and what benefits there would be to develop such compared with e.g. engineering program contents (that could be claimed to "describe" a specific type of engineer), or occupational skills according to ESCO (that describes competencies of a specific type of engineer). By clarifying the *theoretical and practical* implications of the study and its results in the introduction and discussion/conclusions, this will become clearer as well, I believe.	Thank you, this is a driving point for our research. The motivation is now clarified in the **section 1 "Introduction", 5 "Discussion" and 6 "Conclusions"** and 27 new references have been added. However, we need to confirm that we encountered issues in retrieving scientific literature on the two RQs since the engineer archetype (RQ1) seems a novel research area and engineer archetype sustainability assessment (RQ2) is consequently novel. Theoretical and practical implications are also expanded in the revised **section 1 "Introduction**" and **section 5 "Discussion"** as shown in the attached manuscript with revisions highlighted.
Issues connected with archetype definition: When reading the introduction, I got the impression that you wanted to define a standard generic engineering archetype. All engineers have of course something in common, see e.g. the CDIO syllabus (http://cdio.org/framework-benefits/cdio-syllabus) for a comprehensive list covering standard and generic engineering competencies, or different standardisations and accreditations such as the Washington accord. The data set used for creating the archetypes are course syllabi and the ESCO database. These focus on specific types of engineers, and not general features.	We agree. In the revised **section 1 "Introduction"** and the revised **abstract**, we detailed this point. Various national education systems indeed provide guidelines and constraints for the definition of university programs. Our focus is on a scientific methodology for their definition to aggregate the different available experiences, as explained in the revised **section 1 "Introduction"** were we also cited the CDIO syllabus you provided. Moreover, we explained that we aim to develop a general methodology that could work on any engineer (e.g., mechanical, management, electrical, *industrial*) starting from specific course syllabi and occupational competences. In other words, the generated archetype is specific, but the developed method is general.
A mechanical engineer will thus possess other competencies that an industrial engineer.	We agree. Please see the above answer.
1) Why did you choose this approach? 2) and how do you handle the generic vs. specific engineering competencies? Please clarify this better, and also 3) how this is handled in the proposed methodology. 4) What are the benefits with using real syllabi from education programs, and not regulatory documents such as standards, certifications, accreditations, or national regulations?	1) The revised **section 1 "Introduction"** and **section 5 "Discussion"** now explain our intent in mapping specific engineer archetypes in contrast to generic ones. 2) All competences (generic and specific) are accounted for but only for master degree courses. Basic knowledge such as math, physics, and bachelor engineering competences are implicitly embedded and not considered. This information is now

	explicitly stated in the revised **section 3.1. "Archetype Definition".** 3) Please see the answer above. 4) The main benefit of using actual syllabi from education programs and occupational databases, in contrast to regulatory documents, is a specific representation of a particular class of engineers based on existing/actual implementations. This point is now treated in the revised **section 1 "Introduction"** when discussing the RQ1.
Issues connected with archetype definition: Another issue to deal with relates to *limitations*. The journal is an international journal, while you are specifically dealing with European contexts. 1) In what way are your results valid for an international context? 2) Is your methodology applicable internationally, or not, 3) and what measures are suggested if not? This is an issue that affects all parts of the manuscript, but mainly introduction, methodology and conclusions	True. All the points raised are now considered in a new paragraph added in the revised **section 5 "Discussion".** Instead of proposing our work as a "European case study" we have speculated that competences replacement/integration should be considered by those stakeholders who would apply our methodology locally/globally. For example, the United States Occupational Information Network (O*NET) could be adopted as opposed to/together with the ESCO database. Similarly, United States university courses can be used for the SS-ILOs extraction.
Issues connected with archetype definition: The title, "Toward a Sustainable Industry 4.0 Engineer", imply that it is not a traditional type of traditional engineer you are focusing on, like a mechanical, industrial, or automation engineer, but a new concept called Industry 4.0 engineer. It is not obvious what an "Industry 4.0 Engineer" would be, though. 1) Can an industrial engineer be an Industry 4.0 engineer as well? 2) Or are they new types of engineers that require new educational programs and competence profiles in ESCO? Adding all layers and uncertainty of what "engineer" is defined as in the context of the manuscript, it is not easy to address the second question.	True; the revised **title** has removed the ambiguity highlighted. Title keywords (here in *italic*) have been rearranged to highlight *Industry 4.0* as an enabler for defining *engineer archetypes* (RQ1) and evaluating its contribution to *sustainability* (RQ2), but still keeping the title short to emphasize the focus on the selected topics. After removing the ambiguity regarding the I4.0 engineer, the ideas embedded in questions 1) and 2) have been proposed among future research in **sections 4.3 "Interpretation of *Industrial* engineer archetype contribution to Sustainable Development (SD)"** and **5 "Discussion".** We intend to define a method to capture the main patterns of a group of existing (specific) engineer profiles and summarize this information in a representative archetype. Thus, assessing the contribution to SD of the archetype.
Issues connected with sustainability assessment: The sustainability assessment of archetypes is made by considering I4.0 enabling technologies.	Perfect, we confirm your statement.

To be fair, the assessment is therefore regarding the competencies of a specific type of engineer with respect to I4.0 technologies. If this was the intention, then it would be correct.	
However, if so, then crucial data is missing in the manuscript for understanding *how the assessment is made*. In Table 1 a list of the 17 SDGs are found, and in Table 2 a list of enabling I4.0 technologies are found, 1) but which of these elements are contributing to what SDG? 2) And, is this list of 44 enabling technologies a shortlist of a longer list of technologies? You refer to a previous paper, but as a reader I need all information gathered in the current manuscript in order to follow the process. The methodology thus lacks transparency.	1) We have introduced the new **section 2.5, "Industry 4.0 and sustainability",** which provides some background from our preparatory published work. A direct linkage to the new output Table 4 synthesising the impact of the 44 technology elements on the 17 SDGs is now included in the revised **Appendix 1 "*Industrial* engineer A, B and C matrices"**. 2) The 44 technology elements are the final list from our previous published work. Longer lists have not been defined. The revised **section 2.4 "Industry 4.0 (I4.0) and engineering**" clarifies this point. NOTE: We intentionally avoided having more than 44 technology elements. Too much information could be overengineering the mapping process and make it even more challenging to follow.
Moreover, even though the diagrams in Figures 5-8 are quite illustrative, 3) what is the main use of the results? To me, at least, they do not say much more than I already know, i.e. that an industrial engineer would contribute to SDG9 to high extent, which is natural as it is a profession working in the industry. Similarly, if you had made a sustainability assessment of a nurse, I am quite sure that it would score high on SDG3. 4) This issue relates to the first one, i.e. what implications the results have. It is also connected with the inadequate introduction, where clear *motivation* to the research is lacking. 5) Instead of describing the current project (it could be mentioned later on in the manuscript), a thorough discussion regarding the research gaps and needs of being able to assess professions for their contribution towards sustainable development through the enabling technologies of Industry 4.0 should be found, based on *relevant references*. 6) In the introduction, please define key concepts as well, so the reader understands	3) The primary use of the two results of the *industrial* engineer archetype and its contribution to SD have now been more clarified at the two new paragraphs at the beginning of the revised **section 5 "Discussion".** The revised sections **4.3 "Interpretation of *Industrial* engineer archetype contribution to Sustainable Development (SD)** and **6 "Conclusions"** now clarify that as far as sustainability can be pushed, engineers will always have a deep but specific focus on their educational paths and professional careers. These characteristics show the need for an integrated approach to SD by experts from different fields with matching signatures. 4) Please see the answer above. 5) The revised **section 1 "Introduction"** now presents a definition of the gap and motivation based on new and more recent references. As anticipated, 27 new references have been added. The description of the current project has been moved as suggested. 6) Key concepts and terms are now carefully defined in the revised **section 1 "Introduction"** and consistently used

the research of yours.	throughout the manuscript. Two examples are "Sustainable development (SD)" and "archetype".
Methodological issues: While the approach in general seems well working, there are some issues with lack of information (some of the mentioned previously) and procedural descriptions. 1) What problems with validity and reliability could be encountered using your approach? 2) It does not give good support in how to create the SS-ILOs 3) or how to create a suitable team of experts for anyone wanting to use your approach. 4) How many syllabi should be included? 5) How to extract the SS-ILOs? 6) How many experts to include in the panel, and what stakeholders should they represent? Some hints are found in the case study in section 4, but a methodological discussion is lacking.	1) We feel that the method presentations has strongly benefitted from this revision, as highlighted in the attached manuscript with tracked changes, and missing information are now present. From the analysis of the literature, we confirmed that our method for the archetype definition and for the SD mapping are new. In the revised **section 5 "Discussion"** on future work paragraph, we highlighted possible improvements, along with the (known) limitations. 2) In the revised **section 3.1 "Archetype definition"** at step I, detailed information on the generation of the SS-ILOs is reported. 3) Some hints are provided in revised **section 3.1 "Archetype definition"** and **4** "***Industrial* engineer archetype case study"** in which we highlighted how reasonable lower bound for the working group could be at least three institutions, each providing from one to three experts. 4) As stated in the revised manuscript **section 3.1 "Archetype definition"**, a good experimental number of courses is about 50. Therefore, by considering the generation of 2 up to 5 SS-ILOs for each course, about 100 SS-ILOs as initial set can be easily reached. 5) The extraction of SS-ILOs is not straightforward since the input educational and occupation competences in input can vary among the selected institutions and databases. However, since SS-ILOs are quite wide objects, a general definition for their extraction from is probably not possible, because it depends on the specific instance. This concept has been included in the revised **section 3.1 "archetype definition".** 6) The short answer here is probably *the more, the better*: the more are the experts from different frameworks (e.g., academic and occupational), the better the results. The revised **sections 3 "Methodology"** and **4 "*Industrial* engineer archetype case study"** now include this point.
Methodological issues: In the case study, you used 100+ SS-ILOs from 50 courses on the industrial engineering	1) The revised **section 4, "*Industrial* engineer case study",** includes an extended list of the courses considered. Two examples of generated SS-ILOs for one specific course

program. 1) What courses are they? 2) Are they evenly distributed over the, assumingly 7, programs you selected? 3) Why master level? As an active researcher and teacher in engineering, these types of information are very interesting.	have also been included. 2) Yes, these courses have been extracted from the seven universities syllabi of the *industrial* engineering programs. 3) This critical information is now clarified in the revised **section 3.1 "archetype definition"** at stage I of the methodology definition. Thank you for your interest to this matter.
Issues with structure, language and style: The manuscript should be reviewed with respect to *style and language*. Academic texts are characterised by precision, objectivity, and concentration. Precision is achieved e.g. by using consistent terms that are well defined. 1) Many terms are either not well defined such as *"profile"* or *"archetype"*, or inconsistently referred to in the text such as *"educational units / pedagogical units"*. 2) For the area of sustainability, it is recommended to use *"Sustainable development"* whenever possible, because a "sustainable engineer" and a "engineer contributing to sustainable development" are quite different things. 3) Also note that education for sustainable development is not the same as education in sustainability. 4) Quite many abbreviations exist in the manuscript that are not explained, see e.g., Table 3. 5) 2.1 is an introduction to sustainable development and larger than 2.2-2.4. Parts of the section could be removed or moved e.g. to introduction, or consider if both Figure 1 and Table 1 are relevant to include in the manuscript, or if you could merge them. 6) On page 5 in 2.2 you describe CA, TLA and AT. These concepts belong to education sciences, but not particularly education for sustainable development (I for instance use them for all kind of courses). Either clarify how the concepts are connected with education for SD (they could be seen as enablers for instance), or handle the issue in other ways. 7) Similarly, the last paragraph in 2.3 seems misplaced.	These points are probably a consequence of multiple views and contributions coming from 13 authors by 7 countries and have been harmonized thanks to your detailed comments. 1) As anticipated, the terminology has been fully revised. 2) In the revised version, the suggested keyword "Sustainable development" (SD) has been adopted as many times as possible, "sustainable engineer" has been removed from the text, and the suggested "engineer contributing to sustainable development" has been included where relevant. 3) The term "education for sustainable development" (ESD) has been replaced everywhere. 4) All abbreviations are now explained. 5) Figure 2 has been removed. **Section 2.1 "Sustainable Development Goals (SDGs)"** has been dried as much as possible to balance its extension with the other subsections of **section 2 "Background".** 6) As for your suggestion, we have specified that CA can be seen as an enabler for ESD. Moreover, we removed misplaced pieces of information, which we have moved to **section 3.1 "Archetype definition"** for the SS-ILOs definition. 7) The last paragraph has been removed since it provided low added value.
Issues with structure, language and style:	1) English have checked and grammatical

1) Language wise, there are some grammar errors that are at hand, especially in the first part of the manuscript. 2) Some references lack full information in the reference list, and the references have different style, so please review the reference list. 3) Please also review the use of references. The references 2-4 for instance are used to the statement "War, poverty, humanitarian crises, terrorism, migrations, enormous disparities of opportunities, and fragility and inequality of our healthcare systems are examples of these unsolved problems". Ref 2 is definitely addressing these kinds of issues, but refs 3-4 are discussing healthcare and covid, thus quite limited issues.	errors addressed. 2) We tried to fix the references as much as possible. Please see the comment below. 3) The references have been checked both for adequacy and format. We use Mendeley as reference manager system. The IEEE citation style has been chosen, and manual edits have been adopted for style errors. A total of 27 new references has been added. Whenever possible, the old references have been replaced by more recent ones. References 3 and 4 have been removed because of their limited significance as correctly indicated.

Reviewer 3

Comment	***Answer***
Nowadays Industry 4.0 is very important field in Industry, Academia and Society. Development of appropriate competences, skills toward a sustainable Industry 4.0 is a big challenge for our World. The 4th Industrial Revolution is a set of technics, technologies based on fast and reliable communication between machines, robots, devices, humans, computers. Process of preparing consistent program including both industry and academia methodology will evaluate. Feedback from modern factories (I4.0) are needed to improve process of teaching well educated engineers. Methods advisable in this article initiates and promotes the culture of defining and measuring the progress and transition toward the sustainability path. This investigation should be continued to achieve best results. This paper focus mostly on review on the literature and does not deliver new approaches, solutions. This is important to develop new methodology, concept of training, teaching future engineers. Set of competences will extend rapidly and we need to be prepared for this change. Some of real use cases would be better to exhibit implementation of new approach. "Toward a Sustainable Industry 4.0 Engineer" is a significant topic which should be still developed and evaluated. Sustainable Industry 4.0 should be focused not only technical aspects (competences, hard skills) but also soft abilities like good communication, teamwork, etc.	Thank you for this insightful summary about the potential contributions in the investigated area. These clear statements are now part of the revised manuscript, both in the **section 1 "Introduction"** and in the **5 "Discussion"**.
I recommend this article for publication.	Thank you for your time spent on your revision and for your favourable acceptance.

HIGHLIGHTS

- Define standard engineer archetype: integration both academic and occupational I4.0 competences
- Quantify the contribution to Sustainable Development (SD) of standard engineer archetypes
- Realign educational and occupational engineer frameworks to 2030 Sustainable Agenda of the United Nations
- Provide holistic approach, integrating Sustainable Development Goals (SDGs) and I4.0 engineering contents
- Industrial engineer archetype Sustainable Development (SD) contribution

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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Conceptualization, F.L, M.L., A.M., M.M.M. and M.F.; methodology, F.L., M.L; software, F.L.; validation, F.L.; formal analysis, F.L., M.M.M, A.M., M.F, and D.S.; investigation, F.L. resources, M.L.; data curation, F.L.; writing—original draft preparation, F.L., M.L., D.S., M.F., M.M.M., P.M., A.M. and P.L.; writing—review and editing, F.L., M.L., D.S., M.F., M.M.M., P.M., A.M., P.L, E.B., P.F., P.P. R.C., and N.L.; visualization, L.F., M.L. and P.M.; supervision, M.L., E.B., and A.M.; project administration, A.M., and D.S.; funding acquisition, P.F., A.M., M.L., J.B., M.F., D.S. and N.L. All authors have read and agreed to the published version of the manuscript.

Toward a Sustainable Engineer Archetype through Industry 4.0

Authors: Anonymous

Abstract

In the last decade, a shift toward Sustainable Development (SD) in engineering has started in the educational and occupational framework. Therefore, the need to rethink the professional figures of an engineer has become a necessity. Unfortunately, neither a formal methodology to define a standard engineer archetype nor procedural methods to evaluate such archetypes' contribution to SD are investigated. This paper bridges the first gap by proposing a general methodology to define specific engineer archetypes as technical competences from educational - Semi Structured Intended Learning Outcomes (SS-ILOs) - and occupational - European Skills, Competences, Qualifications and Occupations (ESCO)- frameworks. The second gap is addressed by a procedural method based on indirect mapping of the identified archetypes onto United Nations Sustainable Development Goals (UN-SDGs). Since Industry 4.0 (I4.0) is related to engineer archetypes and SDGs, it is used as a bridge. Finally, we provide the application of our proposed methodology to the *Industrial* engineering case study. The results show that significant limitations toward sustainability remain open challenges. However, the intrinsic nature of the *industrial* engineer is confined to some specific goals, and a characteristic signature on sustainability emerged.

Keywords: *industry 4.0, engineer archetype, sustainable development, sustainable engineering, industrial engineering*

1 Introduction

Worldwide Sustainable Development (SD) is one of the most challenging and exciting problems that humanity has ever faced. In the last decades, the uncontrolled anthropogenic impact on the three pillars of sustainability (economic, social, and environmental) caused and worsened many problems within and among countries [1]. It is most probably the major cause of environmental degradation, climate change, and more frequent and intense natural disasters. It also exacerbates the majority of the problems that challenge having a fair life on our planet with dignity and tranquillity. War, poverty, humanitarian crises, terrorism, migrations, enormous disparities of opportunities, and fragility and inequality of our healthcare systems are examples of these unresolved problems [2]. On the other hand, this era has immense opportunities as well as responsibilities.

The 17 Sustainable Development Goals (SDGs) outlined by the United Nations (UN) call on contributions from all the society stakeholders, including local and national governments, non-governmental organisations, and individuals. This universally shared model finally offers the opportunity to address and face such urgent global issues by an integrated view. As described in the SDGs, engaging with sustainability-related problems requires a complete set of knowledge, skills, values, and attitudes which empower individuals to meet current and non-current needs without affecting the ability of future generations [3].

In the last decades, a shift toward SD affects policies, educational and occupational scenarios. The redefinition of the relevant learning objectives that empower learners in the construction of sustainability-related skills are moving toward the "right" direction, and Education for Sustainable Development (ESD) deserves particular merit [4]. Among many areas, engineering education has a potential role in generating a fundamental group of possible change agents that could highly and quickly impact the SDGs fulfilment by informed decisions and responsible actions [5]–[7]. Furthermore, the practical occupational framework can empower new engineers responsible for SD transition [8], [9]. In this framework, we aim to investigate "*How* *much does a specific engineer archetype contribute to SD?".* However, clear procedures on how to define engineer archetypes (e.g., sets of features that characterise specific engineer types) is an open issue that has not received sufficient attention from the scientific community [14]–[16]. Only generic regulatory documents such as standards, certifications, accreditations, and national regulations have been drafted so far [10]–[13]. For this reason, as preparatory work, we aim to explore "*How to define the engineer archetypes?".*

Thus, we will denote the latter question as Research Question 1 (**RQ1**) and the former as **RQ2** since the engineer archetype contribution to SD can be evaluated if an engineer archetype is defined beforehand. After this initial introduction, a more detailed analysis of the two research questions that triggered our work is reported in the following paragraphs.

RQ1: *How to define the engineer archetypes?*

Among others, formally defining a specific type of standard engineer is a crucial aspect that could affect many stakeholders in the educational (e.g., students, professors, universities as institutions) and occupational (e.g., placement services, private companies, public bodies) framework. To develop a general methodology for defining specific groups of engineers, we adopted the concept of abstraction. The main consequence of this abstraction is the definition of typical examples of a particular group of people, things or systems instances whose representative patterns are extracted and formalised in a metamodel, i.e., archetypes [17], [18]. A specific standard engineering archetype (e.g., *industrial* engineer, mechanical engineer, electrical engineer, management engineer) is thus identified as a set of theoretical/practical and actual competences. In more details, these competences, both generic and specific, can be retrieved from engineering educational programs and occupational engineering databases. Thus, program contents or syllabi could be claimed to "describe" a particular type of engineer from an educational perspective. Occupational databases, on the other hand, could offer up-to-date specific labour market related competences.

Both educational and occupational competences are thus considered to define comprehensive archetypes. I4.0 is the common factor among industry and academia that allows grouping of competences from educational and occupational frameworks in the same list. The main benefit of using actual syllabi from education programs and occupational information, in contrast to regulatory documents, is a specific representation of a particular class of engineers based on existing implementations.

Concerning the previously identified stakeholders, benefits and applications due to the definition of an engineer archetype relate to the following activities: evaluation (e.g., SD assessment treated in this work, see the **RQ2**), design (e.g., build or re-design a new program by using the archetype as de-facto baseline), comparison (e.g., compare the existing archetypes in contrast to national, international, and global benchmarks or monitoring trends over time adopting a standard view), and communication (e.g., using the archetype a short and clear manifesto for a specific engineering program).

Summarizing, a general methodology for the abstraction of archetypes as a set of Industry 4.0 (I4.0) related competences is proposed to address the second research question.

RQ2: *How much does a specific engineer archetype contribute to SD?*

A need to assess professions for their contribution towards SD through the enabling technologies of I4.0 is an urgent topic. However, as reported by Stock et al. [19], current research shows that there is still a lack of method-based and quantitative investigations of sustainability impacts of I4.0 as well as of possible contribution to SD. Despite several methodologies on quantitative assessment of I4.0 technologies have been developed (e.g., [20], [21]), and rather significant literature on the sustainability assessment in the educational framework is available (e.g., [5], [22], [23]), a general methodology for the sustainability assessment of engineer archetypes still lacks. Our work is the first attempt at defining engineer archetype in literature, and consequently, its sustainability assessment is implicitly novel. Therefore, to answer the second research question, we propose an evaluation of the engineer archetype contributing to SD by mapping the engineer archetype onto the 17 SDGs indirectly by using I4.0 mapping, as shown in Figure 1. In the first step (arrow B in Figure 1) to connect engineer archetypes and I4.0, we adopted the method developed for the **RQ1**. In the second step (arrow A in Figure 1), we took advantage of our previous work, which proposed a systematic investigation of the influence of the I4.0 technologies onto the UN-SDGs to connect I4.0 to sustainability [24]. Finally, the use of I4.0 paradigm allows the connection of the technical competences characterising engineer archetypes to the sustainable dimension of the SDGs. Hence, the benefit of connecting I4.0 to the left and right side of Figure 1 is the possibility to map how much a specific engineer archetype contributes to SD providing an answer to the **RQ2**. For this reason, since I4.0 represents the core concept of the assessment step, the corresponding box in Figure 1 has been highlighted.

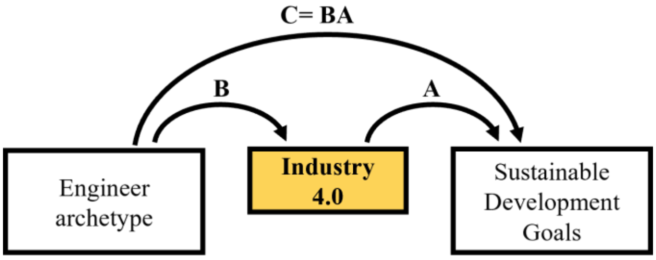

Figure 1: The steps to map the engineer archetype onto SDGs. Arrow **A** represents our previous work [24] where I4.0 has been mapped onto SDGs and resulting in the matrix **A**. Mapping engineer archetype onto SDGs (arrow and matrix **C**) is therefore allowed using a preliminary mapping of the engineer archetype onto I4.0 (arrow and matrix **B**) and using the matrix product.

The main results of this work are thereby i) an approach for defining engineer archetypes and ii) a methodology for assessing engineer archetypes contribution to sustainability.

This paper results from diverse engineering disciplines from seven European higher education organisations (Sweden, United Kingdom, Italy, Portugal, Poland, and Slovenia). A reminder of the structure is detailed here: a background and relevant literature are presented in Section 2. Section 3 describes the methodology for defining engineer archetypes (**RQ1**) and the proposed method to evaluate the sustainability of the archetypes (**RQ2**). In Section 4, an illustrative application of the proposed method is presented for *industrial* engineers, addressing the two questions and providing deep analysis and interpretation of the results. Finally, the discussion and conclusion are presented in Sections 5 and 6, respectively.

2 Background

This section discusses the research background of this work. It starts by providing an overview of UN-SDGs in section 2.1 and continues with a discussion of SD in engineering education and occupational framework in sections 2.2 and 2.3, respectively. Engineering is a significant development in industry and has a substantial effect on sustainability [24]. Section 2.4. discusses this effect, focusing on I4.0 as the dominant industrial paradigm. Finally, the I4.0 and SD relation is discussed in section 2.5.

2.1 Sustainable Development Goals (SDGs)

After developing prior Millennium Development Goals (MDGs), 193 worldwide governments met at the historic UN Summit in September 2015 and agreed to the 17 SDGs and corresponding 169 targets to draw the 2030 Agenda for SD [25]. "*The Goals and targets are the results of over two years of intensive public consultation and engagement with civil society and other stakeholders around the world, which paid particular attention to the voices of the poorest and most vulnerable. The SDGs and relatives' targets are integrated and indivisible, global in nature and universally applicable, considering different national realities and respecting national policies and priorities*" [2].

The extreme degree of complexity resulting from the integration and indivisibility of the 17 SDGs and relatives' targets can be justified by the nature of these goals. The SDGs and targets have been derived using a top-down approach by focusing on sustainability as the highest target for people, the planet, and prosperity, reflecting the 2030 Agenda commitment for SD. A holistic perspective sees the concept of sustainability as a dynamic and evolving combination of interconnected contextual variables (social, economic, and environmental) with temporal considerations (short, medium, and long-term) [26]. The integration and indivisibility of these three pillars reflect in the second level, characterised by a set of interconnected challenging visions (i.e., goals) whose achievement can lead to sustainability. Each goal typically has 8–12 targets, and each target has 1–4 indicators to measure the progress toward reaching the targets. Therefore, the third level represents 169 specific targets for 17 goals, inheriting the integration and indivisibility defined at the root.

Table 1 provides a short description of the 17 SDGs, along with the goals' acronyms and graph legend, which will be referred to in the paper remainder. Tremendous opportunities could be gained based on the SDGs synergies and benefits, cutting down their trade-off. Since the announcement of the SDGs, a growing interest is dedicated to investigating SDGs related aspects, including indicators for goals integrations [27], achievement assessment [28], energy-related targets [29], planet impacts [27], Artificial Intelligence (AI) role [30]–[32], coping with the consequences of economic systems [33], and the influence of the I4.0 on the goals [24].

Table 1: Description of the Sustainable Development Goals (Adapted from [25]).

Sustainable Development Goal (SDG)	Short Description	Graph legend
SDG1: No Poverty	End poverty in all its forms everywhere	
SDG2: Zero Hunger	End hunger, achieve food security and improved nutrition as well as promote sustainable agriculture	
SDG3: Good Health and Well-being	Ensure healthy live and promote well-being for all at all ages	
SDG4: Quality Education	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	
SDG5: Gender Equality	Achieve gender equality by providing equal opportunities for both genders	
SDG6: Clean Water and Sanitation	Ensure availability and efficient management of water and sanitation for all	
SDG7: Affordable and Clean Energy	Ensure access to affordable, reliable, and ecofriendly energy for all	
SDG8: Decent Work and Economic Growth	Promote inclusive economic growth, full and productive employment, and decent work for all	
SDG9: Industry, Innovation, and Infrastructure	Build resilient infrastructure, promote inclusive and eco-friendly industrialisation and foster innovation	
SDG10: Reduced Inequality	Reduce inequality within and among countries	
SDG11: Sustainable Cities and Communities	Make cities and human settlements inclusive, safe, resilient, and eco-friendly	
SDG12: Responsible Consumption and Production	Ensure reasonable and efficient consumption and production patterns	
SDG13: Climate Action	Take urgent action to combat climate change and its impacts	
SDG14: Life Below Water	Considerable consumption and usage of oceans, seas, and marine resources that preserve the for future generations	

SDG15: Life on Land	Protect, restore, and promote responsible use of terrestrial ecosystems and forests, combat desertification, and halt and reverse land degradation and biodiversity losses	
SDG16: Peace and Justice Strong Institutions	Promote peaceful and inclusive societies, provide access to justice for all and build effective, accountable, and inclusive institutions at all levels	
SDG17: Partnerships to achieve the Goal	Strengthen the means to implement and revitalise the global partnership for sustainable development	

2.2 Sustainable Development (SD) in the engineering educational framework

The Sustainable Agenda denotes SDG4: Quality Education as a standalone goal to achieve sustainable education and at the same time as a key enabler in the pursuit of all the remaining 16 SDGs. In this manner, education is viewed as an engine for change through lifelong learning ranging from formal (preschool to tertiary and adult education) to informal education (online courses and self-education) [4]. Education for Sustainable Development (ESD), promoted by the United Nations Educational, Scientific and Cultural Organization (UNESCO), guides education professionals to contribute toward the SDGs achievement [4]. Nowadays, hundreds of millions of people have emerged from extreme poverty within the past generation, and access to education has dramatically increased [2]. However, unfortunately, industrialised countries often prepare students for their competitive participation in the global economy rather than becoming critical and responsible members of society [26].

In the evolution of the classical paradigm of the engineer archetypes, considerable efforts have been dedicated to the realignment of the educational provision to the modern challenges toward engineers contributing to SD [7], [34], [35]. However, as Leifler et al. [5] concluded in their recent study according to Swedish engineering universities and directors of engineering colleges, deep integration of sustainability into the core subjects is lacking. As a result, the progression of sustainability through programs is often weak. Furthermore, the lack of impact of the engineering curricula on specific SDGs, e.g., SDG10, SDG16, and SDG17, have been also highlighted [5]. Such limitations call for studies and approaches that facilitate the design and implementation of educational content which comply with SDGs [36]. However, interpretation of the SDGs in courses design is a complicated process. A valuable enabler that could help in this transition is the formalisation offered by the Constructive Alignment (CA) framework that focuses on the alignment of Intended Learning Outcomes (ILOs), Teaching and Learning Activities (TLAs) as well as Assessment Tasks (ATs) [37].

Accreditation bodies (i.e., The Engineering Accreditation Board (EAB) in the United Kingdom [13], the European Network for Accreditation of Engineering Education (ENAEE) in Europe [12], and the Accreditation Board for Engineering and Technology (ABET) in the United States [11]) have developed their standards covering SD to some extent. As highlighted by recent initiatives, these accreditation bodies and UNESCO are pushing toward establishing a new paradigm for the professional figure of an engineer as a true enabler, equaliser, and accelerator to deliver the SDGs [38]. However, despite numerous guidelines and standards on ESD (e.g., [39]–[41]), an objective understanding of how much a specific engineering archetype contribute to the SDGs is still unesxplored. We only have to assess the achievement of learning outcomes at one point in time at one's disposal, thereby neglecting the actual learning process [5]. Additional works that evaluate the integration of sustainability in higher education [22] and national frameworks for assessing sustainability integration [23] are still far from our aim.

2.3 Sustainable Development (SD) in the occupational engineering framework

As the main result of the education process, the practice of making everyday decisions in occupational and job-related scenarios defines the real impact of engineers on economic, social, and environmental issues [33], [34]. Furthermore, the peculiar huge set of hard skills owned by these practitioners define the related responsibilities for the innovative job ecosystem that account for SD [42]. This aspect of the relationship between technology and sustainability trends determine the critical role of engineers as professional figures that could quickly deliver high impact on SD, as highlighted in [6], [43], [44].

Thus, this influence of technological revolutions toward sustainability highlights the need for professional skills transformation, especially in engineering occupations, which are the ground to foster and realise SD revolutions [42]. As highlighted by Boucher et al. [45], the topical requirements for industrial systems have progressively reintroduced human skills, competences, or know-how as the primary source of industrial performance. However, a significant restriction to the latter aspects is the usual association of soft skills (instead of complex competences) concerning SD and a real marginal commitment from the top management [15], [46].

Indeed, the multilingual classification of European Skills, Competences, Occupations and Qualifications (ESCO) database deserves significant attention when describing, identifying, and classifying actual and up-to-date professional skills that should be gained by the end of a specific qualification (e.g., *industrial* engineer) [47]. The European Commission developed ESCO to map the existing "occupational profiles" in Europe for 27 economic sectors in July 2017. These diverse sectors are taken from the statistical classification of economic activities in the European Community (NACE) [48]. In August 2020, a new version of ESCO was released. It remains a trending tool for both employers and education programs designers in academia and lifelong learning, offering updated information on the new trending skills and systematically showing the semantic relationships between different skills [47].

To define engineers' archetypes, experts of occupational and academic programs must consider overwhelming engineers' competences, spanning from academia to the labour market. By querying the ESCO database, a systematic approach for the latter can be drafted.

2.4 Industry 4.0 (I4.0) and engineering

I4.0 is a well-known vision that describes the introduction and implementation of new technological concepts to fully interconnect production elements by bridging the physical and digital worlds [49], [50]. The integration of Information Communication Technologies (ICT) and industrial technology lead to the creation of a Cyber-Physical System (CPS) to accomplish an intelligent factory promoting a more digital, highly flexible, and green production model [51], [52]. Another essential purpose of this new vision is to build systems with real-time interactions between people, products and devices [53]. Classical engineering domains such as manufacturing, management, informatics, and process technologies deserve significant attention in the rethinking of merging interdisciplinary knowledge with I4.0 enabling technologies [50], [54]. In this framework, our recent paper defined a detailed list of 44 I4.0 technology elements (i.e., E1.1_E9.2) derived from nine well known I4.0 enablers (i.e., E1-E9) [24]. Table 2 summarises a clear definition of the nine enablers [55]–[57] at a lower granularity level to facilitate the technologies' interpretation in the further steps of this work.

Table 2*:* I4.0 enablers and the technology elements (or subenablers) [24].

Enablers	Technology elements
E1 Industrial Internet of Things	E1.1 General Identification E1.2 Ubiquitous Sensing E1.3 Seamless and Real-Time Communication E1.4 Embedded & Edge Computation E1.5 Services Oriented Architecture (SOA) E1.6 Interoperable Semantics Communication
E2 Big Data & analytics	E2.1 Sensors E2.2 Data collecting E2.3 Data processing E2.4 Data querying E2.5 Data access E2.6 Data analytics E2.7 Decision-making support E2.8 Data management techniques and methods

E3 Cloud Computing	E3.1 Computing E3.2 Interoperability E3.3 Servicelisation (on the Cloud) E3.4 Cloud Manufacturing
E4 Simulation	E4.1 Products and processes E4.2 Production lines, workstations, and internal logistics E4.3 Enterprise and its operational environment
E5 Augmented Reality	E5.1 Machine interaction E5.2 Human interaction E5.3 Training E5.4 Communication E5.5 Simulation
E6 Additive Manufacturing (AM)	E6.1 Processes for polymers E6.2 Processes for metals E6.3 Processes for ceramics E6.4 Materials E6.5 Design for Additive Manufacturing E6.6 Software
E7 Horizontal & Vertical System Integration	E7.1 Reference Architecture E7.2 Reference Architecture Model I4.0 (RAMI 4.0) E7.3 Systems Integration E7.4 Digital Twins E7.5 Cyber Physical System E7.6 System of Systems E7.7 Collaborative Networks
E8 Autonomous Robots	E8.1 Perception E8.2 Deliberation E8.3 Autonomy
E9 Cybersecurity	E9.1 Threat identification and detection E9.2 Data loss prevention

As highlighted by Ramirez-Mendoza et al. [53], several efforts have been detonated in the world trying to better understand the evolution in engineering education toward the I4.0, and numerous frameworks for defining new curricula for I4.0 in engineering education have been proposed. Example of such work are reported in the following references: [58], [50], [53], [59]. However, the lack of a systematic and comprehensive procedure for the definition of standard archetype engineer that encompasses both old and new I4.0 competences is still an open issue.

2.5 Industry 4.0 (I4.0) and Sustainable Development (SD)

I4.0 and SD are considered significant trends in the current production system since the former has the unique potential to unlock the latter. Through their synergy, they may together comprise a distinct industrial wave that will change worldwide production systems forever [20].

The rapidly growing interest in the interplay between I4.0 and sustainability from both academia and industry is a fact. In the scientific literature, for instance, please refer to [60]–[64]. As for recent national and international manoeuvres, investments in infrastructure and advanced technological setups or drawing of new standards and regulations, please see, for example, [65]–[67]. This work itself is part of the European Commission Erasmus+ Programme project named “Manufacturing Education for a Sustainable Fourth Industrial Revolution” (MAESTRO) [69].

Within the same framework, our previous paper [24] defines the technology elements but mostly is the first attempt to comprehensively quantify the influence of these I4.0 technology elements on the 17 SDGs. This influence is explicitly stated in the eighth targets of *SDG9: industry, innovation, and infrastructure*, and can be implicitly deduced from the majority of the other 161 targets. Since SDGs aim to provide a blueprint for peace and prosperity for humanity and the earth, the influences of the I4.0 technologies are not equal for all these goals. While the impact is significant and straightforward for some goals, it is minor and indirect on others [24]. The sustainable influence of the I4.0 technologies by mapping these technologies to the SDGs has been identified using a consensus-based quantitative assessment. The output is matrix **A** and itcan be found in Appendix 1, Table 4.

Even though promising technologies should be prioritised and considered in teaching future engineers, an effort is needed to connect the emerging I4.0 technologies into engineering competences. Also, harmonising such transformation with SDGs is still an open gap that the proposed work aims to fill.

3 Methodology

This section provides a detailed description of the suggested methodology to address the two research questions: **RQ1** and **RQ2**. Figure 2 depicts the theory behind this methodology. A procedural method to define archetypes is suggested to address **RQ1,**. The basic information for educational learning outcomes and occupational skills are retrieved from university programs and the ESCO database, respectively, as discussed in section 3.1 (Figure 2, left). Once the archetype has been defined, assessing the sustainability of the defined archetypes (**RQ2**) is the next step. As the direct relation between archetypes and SDGs is challenging to investigate, an indirect quantification of the connection of the archetypes and SDGs through the I4.0 technology is proposed in section 3.2 (Figure 2, right). We provide the *industrial* engineering case study for a practical application and procedural hints and lessons learned (section 4).

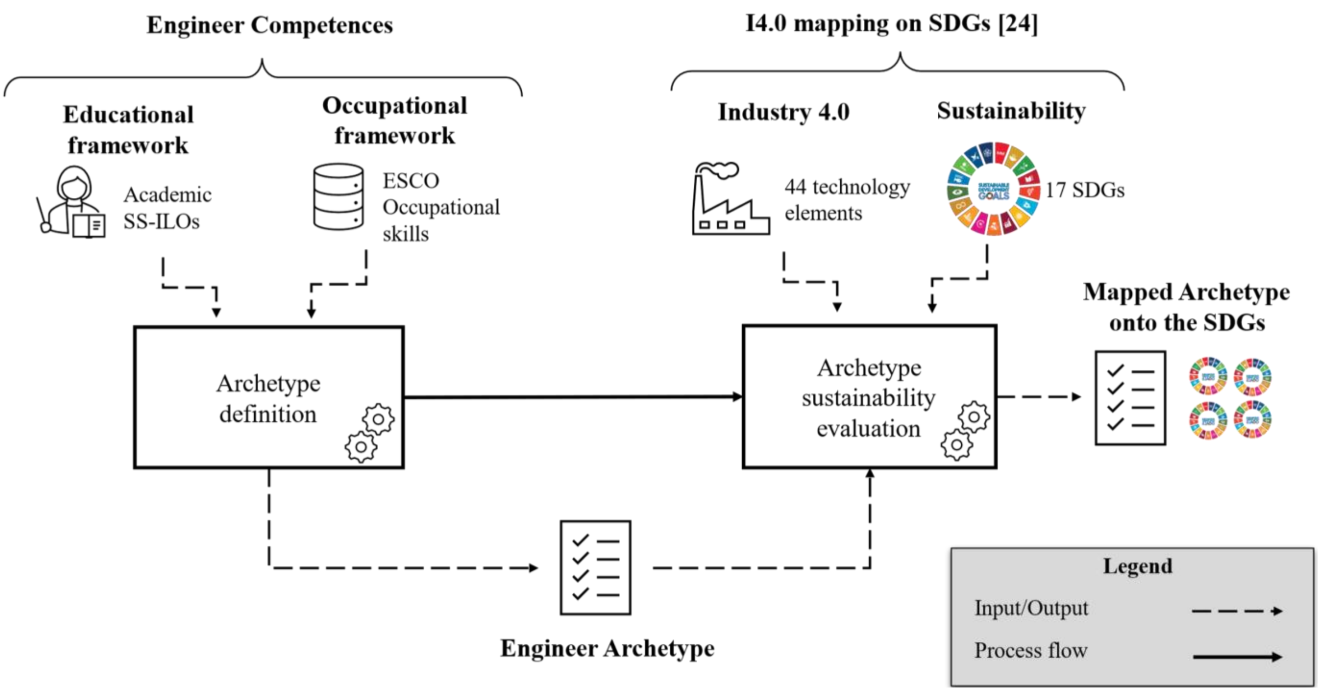

Figure 2: Flowchart of the proposed methodology to define a standard engineer archetype and assess its sustainability through the I4.0 technology elements.

3.1 Archetype definition

As mentioned in the introduction (section1) and background (section 2), standard engineer archetypes have not yet been defined neither in the educational (section 2.2) nor in the occupational (section 2.3) frameworks. To answer **RQ1,** a method to provide the procedural steps for designers of learning frameworks is detailed. This guidance method helps to systematically define standard engineer archetypes through a collaborative working group. The following two types of engineering competences are adopted as input raw data (Figure 2, left):

I. ***Academic SS-ILOs*** are sets of Semi Structured Intended Learning Outcomes derived from the related courses syllabi of the universities program under interest. To maximise the number of SS-ILOs that characterise the archetype, we suggest accounting for all (generic and specific) master's degree courses. Basic knowledge such as math, physics, and other bachelor engineering competences are implicitly embedded in any engineer and less relevant in the characterisation of a specific engineer archetype. From a practical side, a general guideline for construct the SS-ILOs is given as follow:

An ideal number of courses cannot be drafted generally. It depends on the amount of effort in extracting such information and processing time for subsequent activities. However, it is evident that the more courses are offered, the more accurate will be the final archetype. Based on experience, we believe that about 50 courses are sufficient since more extensive sets duplicate the data.

Given a specific course, the SS-ILOs represent a set of sentences - from two to five - depending on the number of delivered topics/credits, which sum up the primary purposes and intended outcomes that the course should achieve. For a specific course, we suggest i)relying on the three pillars of ILOs (i.e., acting verbs, contents, and contexts), ii)focusing on what the students should be able to do at the end of the course, and iii) using from 10 to 25 words [35]. However, since the SS-ILOs are "semi structured," these three pillars' presence is not mandatory. In contrast to the high degree of formality of the well-established ILOs, this solution overcomes different degrees of formalisation from diverse academic institutions. It maximises the generation of information without significant effort, even for those having no experience in CA. Examples are provided in Section 4.1 at step I.

II. ***ESCO Occupational skills*** are skills that characterise the engineering archetype under interest obtained from the ESCO database. As highlighted in section 2.3, this database offers a formal and multilingual classification for the main European professions' skills. Given a specific job, the related skills can automatically be retrieved in the database. Compared to SS-ILOs, this information set presents much more synthetic competences that often embed verbs and contents of the competence itself. Examples are provided in Section 4.1 at step II.

The elements of the two sets are thus grouped, and an initial long list of competences is obtained. After this stage, the competences are clustered through a consensus-based approach by groups of academic experts, which is carried using the structured instructions presented in the next paragraph.

The main task of this activity is the synthesis of the input list to a final set of 5-10 clusters of competences that cover all the identified aspects. The respective clusters of competences hence define the engineer archetype. Duplicated or overlapping courses are to be merged in a fictitious meta course that extracts the main common patterns from diverse instances (e.g., similar courses from different institutions), minimising the information only to the necessary and sufficient. The output of this abstraction is, therefore, a consensus archetype made by a number (e.g., $5<x<10$) of synthetic competence clusters denoted as CL1-CLx that allow relatively easy management for further processing (see section 3.2). For additional information, the *industrial* engineering archetype example is presented in Table 3.

3.2 Evaluation of the engineer archetype contribution to Sustainable Development (SD)

This section describes the suggested method to assess the sustainability of an engineer archetype as defined in section 3.1 and answers the second research question (**RQ2**). The relation between the archetypes and SDGs is complicated and cannot be assessed straightforwardly. Therefore, the assessment is regarding the competences of a specific type of engineer with respect to I4.0 technologies indirectly exploiting the result of mapping the I4.0 technology elements into the SDGs as detailed in [24] and summarised in section 2.5. As shown in Figure 3, the archetype and its contribution to each SDG passing through I4.0 technology elements are summarised by the **A** matrix having E1.1-E9.2 rows and SDG1-SDG17 columns. The assessment is done in two consecutive steps:

I. The ***team scoring*** activity involves assessing the I4.0 technology elements consideration in the archetypes (Figure 3, left). First, the I4.0 technology elements (Table 2) in the archetype is evaluated by a panel of experts. Then, each member of the panel assigns a score for each cluster of competences (CL1-CLx), identified in the previous step (section 3.1), into the 44 technology elements (E1.1-E9.2). A four ordinal correlation measure is used: no correlation, weak, high, and very high correlation that correspond to four possible scores 0, 1, 3 and 9, respectevely; then, the average values from the panel of experts are computed. The result obtained is the **B** matrix having CL1-CLx rows and E1.1.-E9.2 column.

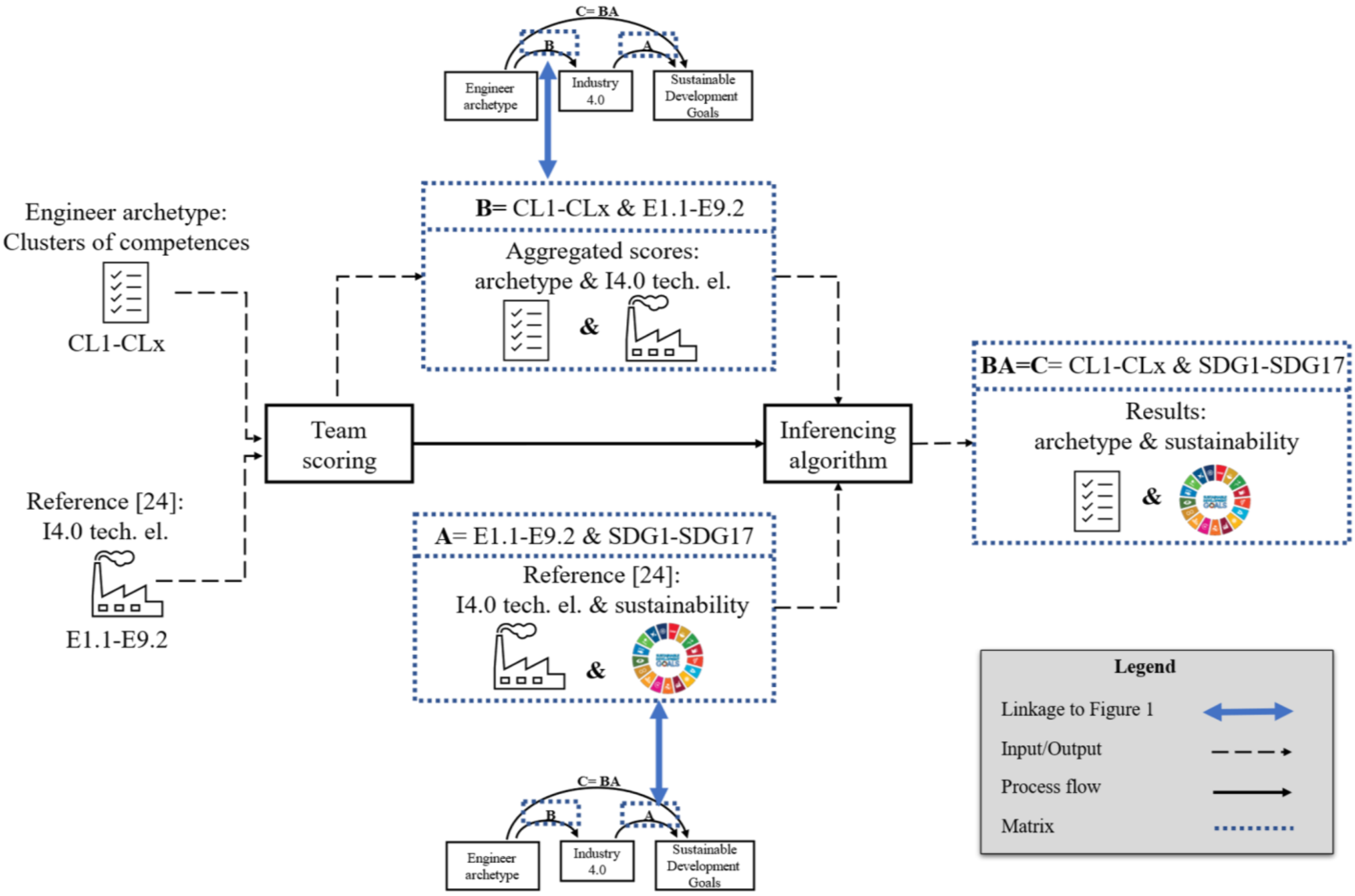

Figure 3: Outline of the proposed method for the sustainability evaluation of the engineer archetype.

II. The ***inferencing algorithm*** is based on the well-known matrix product that works for those matrices that share the same number of rows and columns. The only alteration is to compute a weighted mean, instead of the classical summation, for each output element of the final matrix. As introduced and highlighted in Figure 1, represented as a graphical item in Figure 3, the bridge that links archetype and sustainability is I4.0. Since the two matrices **B** = CL1-CLx & E1.1.-E9.2 and **A** = E1.1- E9.2 & SDG1-SDG12 share the I4.0 technology elements dimension (i.e., E1.1-E9.2), an algebraic product operator can be used. The inferencing algorithm used the team scoring result (matrix **B** in Figure 3) to deduce the sustainability relation via the mapping result in [24] (matrix **A** in Figure 3). The final matrix **C=BA=** CL1-CLx & SDG1-SDG17 thus bridges the CL1-CLx (i.e., the engineer archetype) to each of the 17 SDGs. Each element $\mathbf{C}_{i,j}$ is the weighted average of the products as recalled in Algorithm 1.

For a visual representation of the **A**, **B** and **C** matrices computed in the *industrial* engineer case study presented in section 4, please see the related Appendix 1.

Algorithm 1: Pseudocode used in the inferencing algorithm that indirectly deduces the engineer archetype contribution to SD by computing the weighted average product of the matrices **B** and **A,** resulting in the matrix **C**

```
for j=1 to X [or CL1-CLx]
      for k=1 to 17 [or SDG1-SDG17]
            for i=1 to 44 [or E1.1-E9.2]
                  sum1=sum1 + (Bj,i * Ak,i)
                  sum2= sum2 + (Bj,i)
            end
            The CLj impact onto SDGk is computed as the
            weighted mean, thus Cj,k  = sum1/sum2
      end
      plot the CLj radar diagram by using Cj values
end
```

4 *Industrial* engineer archetype case study

This section illustrates the application of the suggested approach for *industrial* engineering that can be positioned among mechanical, management and production engineering. A careful reading of this section could provide valuable and practical hints as well as good practices and lessons learned discovered during the actual application of the theoretical method proposed in section 3.

As a preparatory activity, the working group needed to be defined. In this case, a total of about 15 experts on *industrial* engineering (professors, PhDs, and researchers) from the seven academic institutions inside the MAESTRO project have been involved. We noticed that a reasonable lower bound could be at least three institutions, each providing from one to three experts.

Applying the two steps of the methodology described in sections 3.1 and 3.2 is used to define an industrial engineer archetype (section 4.1) and evaluate its contribution to SD (section 4.2). Finally, section 4.3 discusses the resulting sustainability evaluation and addresses improvement proposals as well as practical implications.

4.1 *Industrial* engineer archetype definition

An *industrial* engineer archetype has been defined from educational and occupational competences as follows:

I. A set of more than 100 SS-ILOs has been collected from more than 50 courses from master's degree programs in *industrial* engineering distributed from seven European institutions involved in the MAESTRO project (e.g., Advanced Computer-Aided Design (CAD)/ Computer-Aided Manufacturing (CAM) programming, Rapid Prototyping, Advanced Manufacturing Technology, Metrology, Applied Computer Science, Assembly Technology, Automation and robotics, Classical Manufacturing Technology, Computerized Numerical Control (CNC), Design of machines and structure, Digital Factories, Fundamentals of electronics, Industrial plants, production planning and control, Integrated manufacturing systems, Lean manufacturing, Logistics & Supply Chain Management, Machines design, Mechanical materials, Modelling and Simulation of Industrial Processes, Non-conventional manufacturing techniques, Product Lifecycle Management, Quality Control, Recycling).

   The examples of derived SS-ILOs from the syllabus of the Non-conventional manufacturing techniques course are:

   - Analyse advanced additive manufacturing processes, water jet, laser cutting, industrial adhesive bonding and their potentials for new opportunities.
   - Use the full functionality of an advanced CAD modelling software of parts with complex shapes for rapid prototyping.

II. A set of more than 200 occupational skills from the ESCO database for the "*industrial* engineer" archetype (ESCO Code 2141.3.) has been built. For clarity, a subset is reported here: use CAD software, use CAM software, use technical documentation, use thermal analysis provide cost-benefit analysis reports, read engineering drawings, monitor manufacturing quality standards, monitor production developments, evaluate engine performance, examine engineering principles, execute analytical mathematical calculations, execute feasibility study, develop product design, develop software prototype, analyse test data, etc.

This listing of more than 300 competences (100 SS-ILOs + 200 occupational skills) have been further processed by the team members individually and collectively during the online meetings. About 50 duplicate entries have been removed. The remaining competences have been merged to the compact set in the second column of Table 3. A further merging iteration has achieved a manageable number of clusters of competences: CL1-CL6 in the first column of Table 3. Table 3 represents a first attempt in the definition of a standard *industrial* engineer archetype: CL1 is related to both conventional and non-conventional manufacturing processes, including assembly, as well as shop floor design and operations. CL2 is related to structures, machines, and products design, including software, simulations, analyses, experiments, and product data. CL3 focuses on software tools for digital manufacturing. CL4 is related to robotics and automation in general, including sensors, control theory and electronics. CL5 includes production planning and control, maintenance, Health, Safety and Environment (HSE) standards, statistical tools, and system optimisation. CL6 is related to supply chain/network management, including mathematical modelling and managerial topics, financial and economic aspects.

Table 3: The *industrial* engineer archetype and its clusters of competences.

Clusters of competences	Summary of Competences
CL1: Manufacturing Processes	- Design and analyse a plan or specification for designing conventional industrial production systems (e.g., cutting, moulding, deformation, welding). - Design and analyse non-conventional processes (e.g., advanced additive manufacturing, water jet, laser cutting, industrial adhesive bonding). - Design and analyse the best-suited assembly technology, applying technical and economic criteria. - Use specific software for event-driven flow simulation to develop a balanced manufacturing flow within a factory. - Use specific software to develop factory layouts with buildings, manufacturing/assembly systems and factory assets.
CL2: Structures, Machines, and Products Design	- Research on and design for machines and mechanical installations, components, or testing prototypes using Computer Aided Engineering (CAE) tools. - Prepare drawing and technical documentation by applying standards and engineering principles. - Analyse materials' ability to endure stress imposed by temperature, loads, motion, vibration, and other factors using mathematical formulae and simulations. - Conduct research and experiments.
CL3: Production IT Tools Infrastructure	- Practical skills in using CAE software for integrated manufacturing systems (e.g., CAD-Computer Aided Process Planning (CAPP)-CAM). - Evaluate and Select optimal ICT solutions to integrate with hardware systems. - Compare and assess ICT products and services regarding quality, costs, and compliance to specifications. - Design/Select an optimal Product Lifecycle Management (PLM) system for product data control.
CL4: Manufacturing Automation and Robotics	- Apply robot modelling and control theory in robotic stations as well as design and build manufacturing systems. - Select suitable components, control systems and communication technology for automation of material handling and automated assembly. - Assemble robotic machines, devices, and components according to engineering drawings. - Program and install the necessary components of robotic systems, such as robot controllers, conveyors, and end-of-arm tools.
CL5: Production Planning and Control	- Design and optimisation of production planning and adjust work schedules to maintain efficient shift operation. - Plan maintenance processes to ensure satisfactory performance and compliance with specifications and regulations.

	- Use of statistical methods and tools for process monitoring and product measurements. - Apply integrated HSE systems (International Organization for Standardization (ISO) 9001, 14001, 45001 and other standards). - Improve production rates, efficiencies, yields, costs, and changeovers of products and processes. - Plan, monitor and report on the budget.
CL6: Logistics and Supply Chain Management	- Apply mathematical models for anticipating demand, solving/optimisation problems in aggregate planning, inventory management and resource exploitation. - Monitor and control the flow of supplies that includes the purchase, storage, and movement of the required quality of raw materials and work-in-progress inventory. - Manage supply chain activities and synchronise supply with demand of products and customers.

4.2 Evaluation of the *Industrial* engineer archetype contribution to Sustainable Development (SD)

Output from the team scoring activity is presented in section 3.2 at step I, where five different teams have provided five independent sets of scores within the project consortium. Each team has blindly assigned a correlation score on how each identified six competence clusters (CL1-CL6) is aligned to I4.0 technology elements (E1.1-E9.2). Table 5 in Appendix 1 shows the average scores for the final matrix **B**.

By following the methodology presented in section 3.2 at step II, and using the matrix **A** in Table 4 (Appendix 1), the final matrix **C**=**BA** with weighted elements is computed. The final result is reported in Table 6, Appendix 1.

A visual representation of the results in the form of radar plots that highlights a typical "signature" of the *industrial* engineer is obtained using the final scores of matrix **C** (see Figure 4).

The following observation emerged from the *industrial* engineer case study. The graphical representation for the six clusters (CL1 to CL6), i.e., the radar plots, display the weighted mean values obtained by the computation Algorithm 1, normalised in the 0-100 range for the 17 SDGs. Each cluster of competences CLx presents the same shape, which can be observed for all the six clusters of competences of an *industrial* engineer. However, only some of the SDGs are aligned to the competences of an *industrial* engineer. Despite the different technological imprinting that characterises the identified clusters of competences, a one-to-one comparison between each cluster highlights an evident recurrent and confined pattern. For a broader discussion, see Appendix 2.

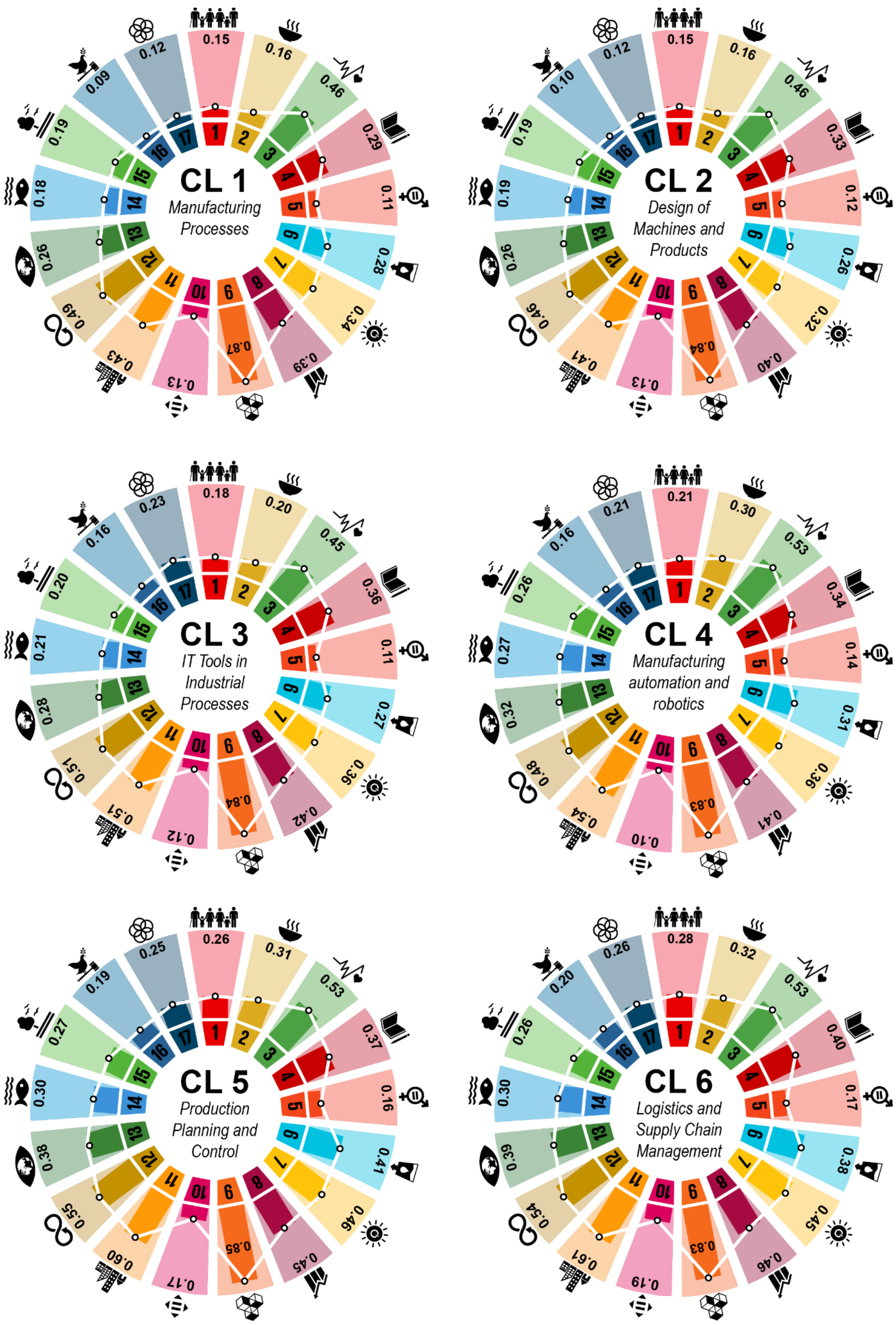

Figure 4: Sustainability mapping on the 17 SDGs of the proposed *industrial* engineer archetype.

4.3 Interpretation of *Industrial* engineer archetype contribution to Sustainable Development (SD)

For a deeper understanding of the results in Figure 4, the score distribution is further investigated. Figure 5 shows the variability of the weighted average of each SDG score, given by the teams of experts, output from the inferencing algorithm. The boxplots are based on the values of the radar diagrams in Figure 4, considering each team separately. At a glance, SDG9 is the goal that presents the lowest variability and the highest weighted mean. After all, the intrinsic relation with I4.0 and *SDG9: Industry, Innovation, and Infrastructure* is intuitive and demonstrated by the unanimous scores. Conversely, *SDG 11: Make cities and human settlements inclusive,* *safe, resilient, and eco-friendly* presents the highest variability showing the different perspectives of this goal. *SDG5: Gender Equality* and *SDG10: Reduced Inequality* present the lowest weighted means with low variability, thus demonstrating the limited impact that an *industrial* engineer can have on those aspects.

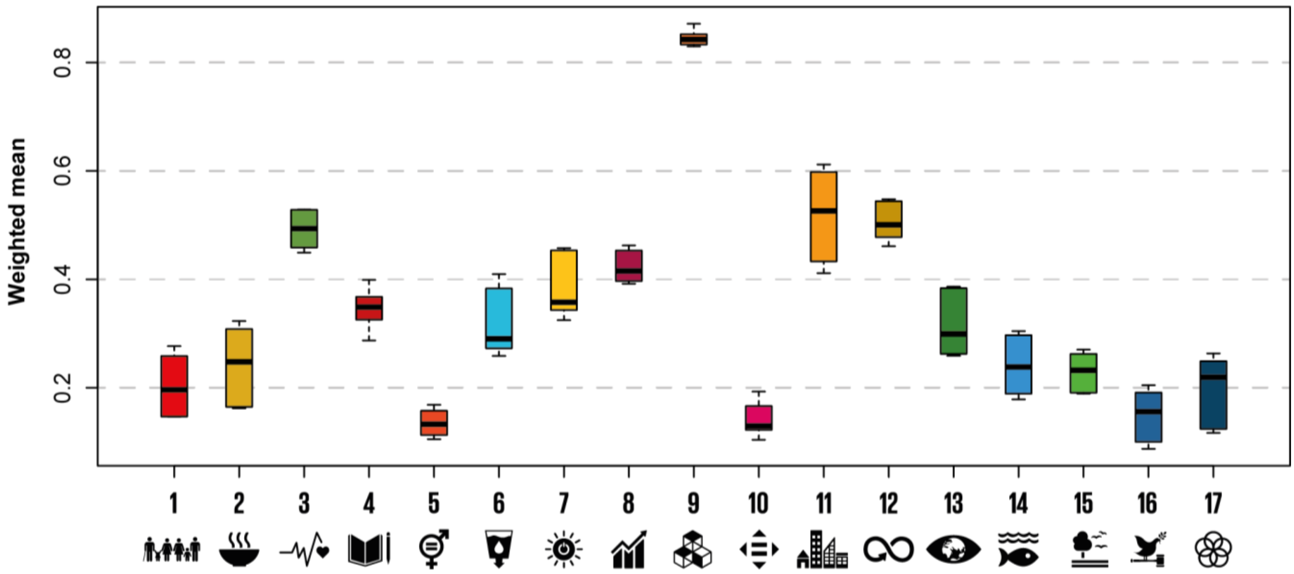

Figure 5: Boxplots of the distribution of the weighted mean of each SDG score, given by the teams of experts, output from the inferencing algorithm.

Summarizing, the identified signatures of Figure 4 could be justified by the argument that I4.0 technology elements will have an unequal influence on the goals. For example, an *industrial* engineer would contribute to SDG9 to a greater extent than other SDGs since it works in the industry. As shown in Figures 4 and 5, the effect of I4.0 is mainly covering SDG3, SDG9, SDG11 and SDG12 in all the six CLx. Taking CL6 and CL1 as an example of the highest absolute difference (still relatively low) observed in the pairwise comparison among clusters of competences, additional observations follow. CL6 presents a better overall impact on all the 17 goals except SDG9 because logistic and supply chain is a set of topics embedded in the management scenario that significantly affects the SD aspects. On the other hand, CL1 is relatively confined to heavy technical disciplines related to manufacturing processes.

The above mentioned considerations mainly apply to the other engineer archetypes, which include technical and managerial skills, which are nevertheless required by an integrated view according to the 17 UN-SDGs. However, the next generation of engineer archetypes should consist of more social and environmental aspects to encompass a holistic approach to contribute to SD [34] significantly. Tejedor et al. [70] stated that an engineer contributing to SD requires creating new long-term, participatory, solution-oriented programs. This approach, which is pretty far from being reached, would provide platforms to recognise and engage with the macro-ethical, adaptive, and cross-disciplinary challenges [71].

Despite the answers to the paper's two research questions, this work opens even more research questions: Does a more standard description for *industrial* engineers exist in contrast to the one depicted in this paper? What are the constraints to "extend" the identified *industrial* engineer sustainability signature? What can remove the "inertia effect" that frequently freezes the improvement dynamics due to lack of communication between different disciplines, bureaucracy, and competition or external barriers? [5].

We still believe that many studies, implementation cases, and dissemination events are needed toward sustainable curricula in *industrial* engineering, which is the starting point.

5 Discussion

The development of frameworks such as the one presented in this work stimulates the standardisation of engineers. Furthermore, it contributes to encouraging SD contribution evaluation by using the I4.0 revolution as the core concept.

Briefly focusing on the possible uses of the results provided for the *industrial* engineer case study we recall:

- Use the generated *industrial* engineer archetype (see Table 3) as a baseline for those stakeholders involved in courses design, communication, comparison and evaluation. It could provide new ideas and align education programs from diverse institutions or training courses from different companies.
- Use the analysis conducted to evaluate the *industrial* engineer archetype contribution on SD for the redefinition of the SS-ILOs. For example, new courses could embrace specific I4.0 technology elements filling the gap on particular SDGs. However, to insert new courses in the current archetypes, a fundamental constraint must be evaluated: a specific course must increase the SD of the overall program. This constraint can be assessed using the "as is" mapping provided in Figure 4, in contrast to the "to be" or future mapping. In this framework, the MAESTRO partners are currently investigating methods to improve old and new *industrial* engineer educational SS-ILOs on SD.

The proposal of a methodology for a *standard* engineer archetype definition as the answer to the **RQ1** is the milestone for numerous stakeholders that seek to evaluate, design, compare or communicate a specific type of engineer. Furthermore, as demonstrated in this work, the preparatory step of archetype definition opens numerous applications, such as answering the **RQ2** by developing a method for "as is" (or "to be") mapping and evaluation of how much the archetype contributes to SD.

Beyond the latter, numerous frontiers can be explored, and uncountable applications can be implemented. For example, as a natural consequence of the SD contribution evaluation, it is possible to measure the progress in the transition toward SD. These measures provide a ground to define educational courses for academic and occupational learning and harmonise it with the SDGs. Notably, when, such as nowadays, the set of competences will extend rapidly, we will need to be prepared for this change.

Our aim is thus to develop a framework that could provide tools, methodologies, and hints to promote a structured approach in contributing to the archetype definition and SD by using I4.0 as a core concept for engineering disciplines. Furthermore, since we focused on the European scenario, competences replacement/integration should be considered by those stakeholders who would apply our methodology locally/globally. For example, the United States Occupational Information Network (O*NET) [72] could be adopted as opposed to/together with the ESCO database. Similarly, United States university courses can be used for the SS-ILOs extraction.

As for future development, we aim to address the following points.

- ***Improve the archetype definition methodology:*** The proposed methodology for defining archetypes can be improved by a more systematic and automated input of competences: SS-ILOs and occupational skills. Text mining [73] method for automatic archetype definition is currently under development and promising partial results have been raised.
- ***Multidisciplinary collaboration for defining the archetypes:*** The proposed method's reliability and validity can be improved by the partnership of experts from academia, research, industry globally or locally. With a particular focus on integrating the industry perspective in the working team, we suggest at least one figure from the industry. Increasing the feedback and connection from modern I4.0 factories to academic experts would align educational and occupational I4.0 competencies in a transdisciplinary way [74].

- ***Alternative archetypes and SD contribution assessment:*** Possible application for the archetype definition can be extended to non-engineering figures, e.g., economics, mathematics, life, art and social sciences, by following the same approach based on SS-ILOs and occupational skills. However, extending the mapping of the SDGs to a general archetype without passing through the I4.0 technologies requires investigation, particularly involving non-technical profiles in which a weaker connection to I4.0 exists. For this reason, we would integrate soft skills (e.g., good communication, teamwork) with hard skills (I4.0 technical aspects) that characterise our method. This integration could allow the adoption of such mapping method even to non-I4.0 related archetypes and increase the related (i.e., engineering) validity [75].

Procedural approaches are needed to harmonise existing content with SD and add new contents that could speed the transition toward sustainability. This article's methods initiate and promote the culture of defining and measuring the progress and evolution toward the SD path. We hope that additional actual use cases, worldwide contributions and investigation on this tremendously important topic would enhance the proposed framework.

6 Conclusion

This paper has investigated the extent to which an industrial or I4.0 engineer can realise the 2030 Sustainable Agenda of the United Nations strategic objectives. We started by defining a standardised professional archetype, integrating academic and occupational skills. Then, a method to quantify its SD contribution has been proposed: indirectly through a mapping of I4.0 on the SDGs. This method initiates and promotes defining and measuring the progress and transition toward the SD path.

The proposed method has been applied to define an *industrial* engineer archetype; its main competences CLx are clustered in six areas. The 44 I4.0 technology elements have been mapped on these clusters and the UN-SDGs. The SDGs standardised view provides a holistic approach, integrating SD and I4.0 contents. Observing the intersection between SD and *industrial* engineer archetypes, it is no surprise that a high degree of sustainability is present. Both I4.0 enablers and SD principles have been present in engineering archetypes for a long time. However, a confined impact on particular SDGs has been observed. Thus, while there may be an evolution of the current *industrial* engineer archetype SD, there is no certainty that it will significantly impact the trilobate-shaped SDG signature shown in the radar plots. As far as sustainability can be pushed, engineers will always have a deep but specific focus on their educational paths and professional careers. These characteristics show the need for an integrated approach to SD by experts from different fields with matching signatures.

As a final conclusion, we argue that (industrial) engineers and no single discipline on its own scarcely present a solution for achieving all the SDGs. This fact is mainly due to the intrinsic integrated and indivisible balancing on the three economic, social, and environmental dimensions of SD. These dimensions need support from professionals with different backgrounds to achieve an actual integrated coverage of SDGs through interdisciplinary approaches, which can be objectively identified by the method proposed in this paper.

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Appendix 1: *Industrial* engineer A, B and C matrices

A			Sustainable Development Goals																
			SDG1	SDG2	SDG3	SDG4	SDG5	SDG6	SDG7	SDG8	SDG9	SDG10	SDG11	SDG12	SDG13	SDG14	SDG15	SDG16	SDG17
Industry 4.0	E1	E1.1	0.24	0.29	0.57	0.24	0.10	0.29	0.33	0.38	0.90	0.19	0.52	0.48	0.33	0.29	0.33	0.10	0.24
		E1.2	0.24	0.38	0.62	0.10	0.10	0.38	0.33	0.29	0.81	0.10	0.71	0.57	0.33	0.33	0.43	0.10	0.14
		E1.3	0.24	0.38	0.57	0.43	0.05	0.33	0.43	0.43	0.90	0.05	0.81	0.62	0.14	0.10	0.19	0.10	0.19
		E1.4	0.19	0.14	0.67	0.48	0.05	0.48	0.48	0.33	0.90	0.00	0.57	0.52	0.38	0.38	0.38	0.24	0.19
		E1.5	0.33	0.33	0.67	0.43	0.14	0.38	0.48	0.48	0.90	0.19	0.81	0.57	0.33	0.29	0.29	0.33	0.33
		E1.6	0.14	0.14	0.43	0.24	0.05	0.29	0.33	0.29	0.71	0.05	0.67	0.38	0.24	0.14	0.19	0.14	0.24
	E2	E2.1	0.24	0.33	0.76	0.10	0.14	0.62	0.48	0.38	0.81	0.10	0.71	0.57	0.62	0.52	0.52	0.19	0.10
		E2.2	0.43	0.52	0.67	0.52	0.24	0.62	0.62	0.52	0.71	0.29	0.81	0.48	0.71	0.52	0.38	0.33	0.29
		E2.3	0.38	0.48	0.67	0.48	0.33	0.62	0.62	0.48	0.71	0.33	0.81	0.57	0.67	0.57	0.43	0.43	0.48
		E2.4	0.38	0.48	0.57	0.48	0.24	0.48	0.38	0.33	0.62	0.19	0.52	0.52	0.48	0.38	0.33	0.33	0.33
		E2.5	0.33	0.24	0.67	0.62	0.29	0.62	0.43	0.52	0.81	0.24	0.62	0.52	0.57	0.48	0.33	0.33	0.33
		E2.6	0.38	0.57	0.67	0.52	0.33	0.71	0.62	0.19	0.81	0.19	0.81	0.57	0.62	0.52	0.38	0.33	0.38
		E2.7	0.71	0.81	0.76	0.62	0.33	0.81	0.71	0.52	0.90	0.38	1.00	0.57	0.71	0.62	0.48	0.43	0.48
		E2.8	0.38	0.48	0.57	0.43	0.29	0.62	0.62	0.52	0.81	0.48	0.71	0.48	0.52	0.38	0.38	0.33	0.33
	E3	E3.1	0.33	0.29	0.33	0.38	0.05	0.14	0.29	0.05	0.90	0.10	0.67	0.52	0.14	0.10	0.10	0.19	0.38
		E3.2	0.14	0.24	0.29	0.19	0.05	0.24	0.38	0.33	0.90	0.00	0.76	0.43	0.14	0.10	0.10	0.33	0.52
		E3.3	0.10	0.10	0.24	0.48	0.05	0.10	0.48	0.52	0.90	0.29	0.62	0.57	0.24	0.05	0.05	0.19	0.38
		E3.4	0.14	0.05	0.05	0.24	0.00	0.05	0.33	0.33	1.00	0.10	0.33	0.43	0.19	0.00	0.00	0.14	0.29
	E4	E4.1	0.14	0.05	0.33	0.43	0.05	0.33	0.38	0.62	0.90	0.10	0.43	0.62	0.24	0.19	0.14	0.05	0.05
		E4.2	0.14	0.10	0.43	0.29	0.05	0.14	0.38	0.57	0.81	0.10	0.38	0.71	0.14	0.00	0.05	0.00	0.00
		E4.3	0.05	0.10	0.48	0.29	0.05	0.29	0.43	0.62	0.81	0.05	0.43	0.57	0.19	0.10	0.10	0.00	0.10
	E5	E5.1	0.05	0.10	0.48	0.81	0.24	0.05	0.14	0.62	0.90	0.14	0.14	0.24	0.24	0.14	0.14	0.00	0.00
		E5.2	0.14	0.10	0.52	0.81	0.38	0.05	0.10	0.71	0.90	0.19	0.43	0.48	0.29	0.29	0.29	0.14	0.29
		E5.3	0.24	0.10	0.52	0.90	0.33	0.05	0.29	0.71	0.81	0.24	0.43	0.43	0.29	0.19	0.19	0.05	0.19
		E5.4	0.10	0.05	0.52	0.71	0.19	0.10	0.19	0.52	0.81	0.19	0.48	0.57	0.38	0.33	0.33	0.19	0.24
		E5.5	0.05	0.05	0.48	0.71	0.24	0.05	0.19	0.52	0.81	0.14	0.29	0.38	0.29	0.24	0.29	0.05	0.00
	E6	E6.1	0.00	0.00	0.38	0.10	0.05	0.24	0.24	0.19	1.00	0.14	0.24	0.43	0.24	0.14	0.19	0.00	0.00
		E6.2	0.00	0.00	0.38	0.05	0.05	0.24	0.24	0.19	1.00	0.14	0.24	0.48	0.24	0.05	0.10	0.00	0.00
		E6.3	0.00	0.00	0.38	0.05	0.05	0.24	0.33	0.19	0.90	0.14	0.29	0.43	0.10	0.00	0.05	0.00	0.00
		E6.4	0.10	0.10	0.48	0.10	0.10	0.29	0.33	0.29	0.90	0.14	0.29	0.43	0.19	0.14	0.19	0.00	0.00
		E6.5	0.00	0.00	0.38	0.10	0.05	0.05	0.14	0.29	0.71	0.05	0.14	0.29	0.05	0.00	0.05	0.00	0.00
		E6.6	0.00	0.00	0.29	0.10	0.05	0.05	0.14	0.29	0.71	0.05	0.10	0.29	0.05	0.00	0.00	0.00	0.00
	E7	E7.1	0.05	0.10	0.10	0.05	0.00	0.19	0.24	0.19	0.71	0.05	0.29	0.52	0.05	0.00	0.05	0.00	0.19
		E7.2	0.10	0.10	0.19	0.14	0.00	0.14	0.24	0.38	0.81	0.00	0.14	0.48	0.05	0.05	0.05	0.00	0.05
		E7.3	0.14	0.19	0.48	0.24	0.05	0.19	0.38	0.57	1.00	0.10	0.57	0.62	0.24	0.19	0.24	0.14	0.33
		E7.4	0.14	0.19	0.33	0.29	0.05	0.24	0.43	0.48	1.00	0.05	0.48	0.57	0.14	0.14	0.19	0.14	0.29
		E7.5	0.14	0.14	0.48	0.38	0.10	0.24	0.38	0.52	1.00	0.05	0.48	0.57	0.33	0.19	0.19	0.14	0.38
		E7.6	0.10	0.10	0.38	0.24	0.05	0.19	0.33	0.43	0.81	0.05	0.38	0.52	0.24	0.19	0.19	0.05	0.29
		E7.7	0.48	0.52	0.43	0.38	0.14	0.29	0.52	0.43	0.90	0.24	0.71	0.52	0.24	0.29	0.19	0.33	0.57
	E8	E8.1	0.14	0.48	0.52	0.14	0.19	0.14	0.19	0.33	0.81	0.00	0.38	0.33	0.29	0.33	0.29	0.14	0.14
		E8.2	0.14	0.38	0.52	0.24	0.29	0.24	0.29	0.33	0.81	0.00	0.38	0.33	0.29	0.33	0.29	0.14	0.14
		E8.3	0.19	0.43	0.62	0.24	0.10	0.10	0.14	0.33	0.76	-0.1	0.43	0.24	0.24	0.24	0.24	0.05	0.05
	E9	E9.1	0.10	0.10	0.43	0.24	0.05	0.24	0.19	0.29	0.62	0.05	0.62	0.38	0.05	0.05	0.05	0.33	0.33
		E9.2	0.10	0.10	0.43	0.19	0.05	0.29	0.24	0.29	0.62	0.05	0.62	0.43	0.19	0.14	0.14	0.33	0.33

Table 4: Matrix **A** = E1.1- E9.2 & SDG1-SDG12 as a result of our previous paper [24]. The values have been normalised to the maximum value of 3 to provide a 0-100 range. Please note how **A** share the same I4.0 technology elements dimension (i.e., E1.1-E9.2) as the matrix **B** shown in Table 5.

B		Industry 4.0																	
		E1						E2								E3			
		E1.1	E1.2	E1.3	E1.4	E1.5	E1.6	E2.1	E2.2	E2.3	E2.4	E2.5	E2.6	E2.7	E2.8	E3.1	E3.2	E3.3	E3.4
Industrial Engineer Archetype	CL1	1.00	3.00	2.25	2.25	0.75	0.75	1.50	0.75	0.75	0.25	0.25	0.75	4.50	0.75	0.75	0.25	0.75	0.75
	CL2	0.75	0.25	0.75	1.00	0.25	0.25	2.75	1.00	0.75	0.75	0.75	2.25	2.25	2.50	2.50	0.75	0.25	0.75
	CL3	4.00	1.50	5.25	5.25	1.00	0.75	3.25	3.75	1.50	3.75	3.25	3.00	3.00	3.25	4.00	5.25	5.00	3.50
	CL4	7.00	2.25	3.75	3.25	1.75	1.75	3.75	3.25	1.50	1.00	1.00	2.25	4.75	1.00	2.25	0.75	0.75	1.00
	CL5	1.75	1.00	0.25	0.75	0.25	0.75	3.00	3.25	5.50	0.75	0.75	6.00	7.00	1.50	0.25	0.25	0.25	0.25
	CL6	3.25	1.00	1.00	0.25	1.00	0.25	1.00	4.75	5.00	0.25	0.25	3.00	4.75	2.75	0.75	0.25	1.50	0.75

B		E4			E5					E6					
		E4.1	E4.2	E4.3	E5.1	E5.2	E5.3	E5.4	E5.5	E6.1	E6.2	E6.3	E6.4	E6.5	E6.6
Industrial Engineer Archetype	CL1	7.00	6.00	3.50	0.75	0.50	2.50	0.75	2.50	7.00	7.50	5.50	4.00	3.50	3.00
	CL2	6.00	3.75	1.75	3.00	1.00	0.50	1.00	5.25	2.75	2.75	2.75	5.00	7.50	4.50
	CL3	6.00	4.50	3.25	1.50	1.75	3.25	5.25	5.25	1.75	1.25	1.25	0.25	4.50	3.75
	CL4	3.00	3.00	3.00	1.00	0.75	0.75	2.25	2.25	0.25	0.25	0.25	0.25	1.00	1.00
	CL5	5.50	4.00	4.00	0.25	0.25	1.00	0.25	0.25	1.00	1.00	1.00	1.00	1.00	0.25
	CL6	2.00	7.00	1.75	0.25	1.00	0.50	1.00	1.00	0.25	0.25	0.25	0.25	0.25	0.25

B		E7							E8			E9	
		E7.1	E7.2	E7.3	E7.4	E7.5	E7.6	E7.7	E8.1	E8.2	E8.3	E9.1	E9.2
Industrial Engineer Archetype	CL1	0.25	0.25	0.75	1.00	0.25	0.75	0.75	1.00	1.00	1.00	0.33	0.25
	CL2	0.25	0.25	0.25	0.50	0.75	0.75	0.75	0.75	0.75	0.75	0.25	0.25
	CL3	5.50	3.00	7.50	5.50	4.00	4.50	1.50	0.75	0.75	0.75	3.50	3.50
	CL4	2.50	0.50	1.50	1.00	3.00	1.50	0.50	6.00	6.00	7.50	1.00	1.00
	CL5	1.00	0.50	5.50	4.75	0.75	1.00	0.75	0.25	0.25	0.75	0.25	0.25
	CL6	1.00	0.50	1.25	0.25	1.00	1.00	2.25	0.50	0.50	0.33	0.50	0.50

Table 5: Matrix **B** = CL1-CLx & E1.1.-E9.2 results from the approach described in section 4.2. Please note how **B** shares the same I4.0 technology elements dimension (i.e., E1.1-E9.2) as the matrix **A** shown in Table 4,

C		Sustainable Development Goals																
		SDG1	SDG2	SDG3	SDG4	SDG5	SDG6	SDG7	SDG8	SDG9	SDG10	SDG11	SDG12	SDG13	SDG14	SDG15	SDG16	SDG17
Industrial Engineer Archetype	CL1	0.15	0.16	0.46	0.29	0.11	0.28	0.34	0.39	0.87	0.13	0.43	0.49	0.26	0.18	0.19	0.09	0.12
	CL2	0.15	0.16	0.46	0.33	0.12	0.26	0.32	0.40	0.84	0.13	0.41	0.46	0.26	0.19	0.19	0.10	0.12
	CL3	0.18	0.20	0.45	0.36	0.11	0.27	0.36	0.42	0.84	0.12	0.51	0.51	0.28	0.21	0.20	0.16	0.23
	CL4	0.21	0.30	0.53	0.34	0.14	0.31	0.36	0.41	0.83	0.10	0.54	0.48	0.32	0.27	0.26	0.16	0.21
	CL5	0.26	0.31	0.53	0.37	0.16	0.41	0.46	0.45	0.85	0.17	0.60	0.55	0.38	0.30	0.27	0.19	0.25
	CL6	0.28	0.32	0.53	0.40	0.17	0.38	0.45	0.46	0.83	0.19	0.61	0.54	0.39	0.30	0.26	0.20	0.26

Table 6: Matrix **C** =**BA**= CL1-CLx & SDG1-SDG12 results from the approach described in section 4.2. Please note how the I4.0 technology elements allowed the algebraic product between **BA**.

Appendix 2: Detailed discussion on the *Industrial* engineer archetype contribution to SD

Based on the values of the weighted average (Table 6, Appendix 1), five groups are identified by hierarchical clustering of the 17 SDGs as shown in the dendrogram in Figure 6 and have been characterised as follows:

- ***Red SDG-Group:*** *SDG9: Industry, Innovation, and Infrastructure*. As previously highlighted, the *industrial* engineer archetype highly addresses this SDG since it is the core of I4.0.
- ***Light blue SDG-Group:*** *SDG3: Good Health and Well-being*, *SDG11: Sustainable Cities and Communities*, *SDG12: Responsible Consumption and Production*. This group includes technical aspects that combine policymaking and cultural habits. As an example, engineers might play a significant role in responsible production. Still, on the other hand, responsible consumption depends on the consumer attitude or regulations imposed by central or local governments outside of the *industrial* engineer field of work.
- ***Purple SDG-Group:*** *SDG4: Quality Education*, *SDG6: Clean Water and Sanitation*, *SDG7: Affordable and Clean Energy*, *SDG8: Decent Work and Economic Growth*, *SDG13: Climate Action*. Similarly to the above Group, these SDGs require a combination of technical actions with policies and culture. For example, engineers may affect the production system efficiency or water treatment plants. Nevertheless, pushing on the achievement of the SDGs of these groups also requires a fundamental contribution from policymakers.
- ***Green SDG-Group:*** *SDG1: No Poverty*, *SDG2: Zero Hunger*, *SDG14: Life Below Water*, *SDG15: Life on Land*, *SDG17: Partnerships to achieve the Goal*. In this group of SDGs, policymaking and economic factors play a predominant role over technical aspects.
- ***Gold SDG-Group:*** *SDG5: Gender Equality*, *SDG10: Reduced Inequality*, *SDG16: Peace and Justice Strong Institutions.* These SDGs are more related to humanities and social disciplines, and therefore, relatively far from engineering aspects. Therefore, additional and interdisciplinary expertise is needed to address the goal within these SDGs in cooperation with industrial engineers.

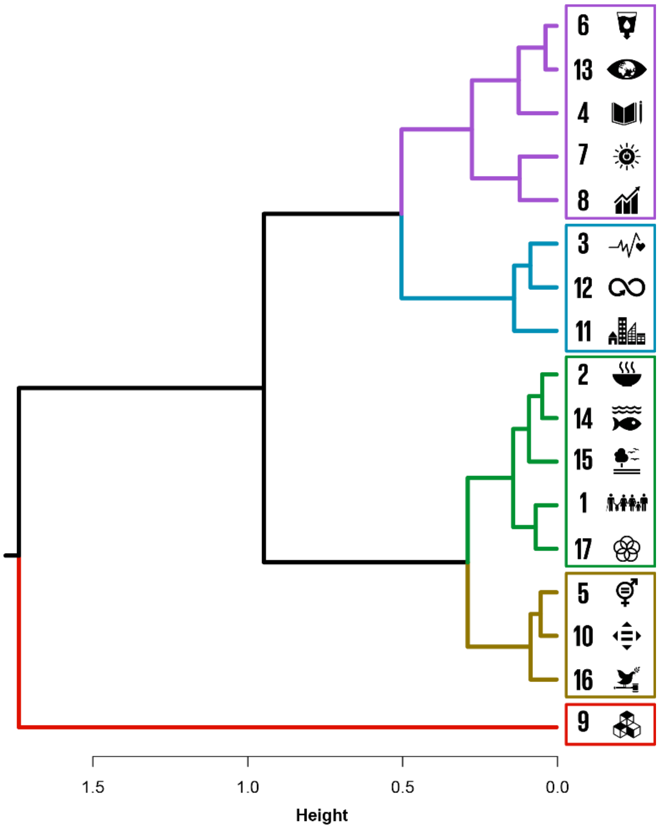

Figure 6: Hierarchical clustering of the SDGs

These analyses reinforce our idea that, for significant coverage of the SDGs, the gap should be filled through the support of experts on the related topics in a contamination framework. A multidisciplinary team is likely to possess a broader range of sustainability abilities, knowledge and skills, and members with different perspectives give a larger pool of resources. Such a diversified team may help deal with non-routine issues for more creative and innovative problem-solving approaches that could encounter success in a sustainable manner [71]. If reversed, this concept stays true: different professional aspects may require support from (industrial) engineers for an integrated action toward SD.

Similar hierarchical clustering analysis on the resulting clusters of competences of the *industrial* engineer has been carried out as shown in the dendogram of Figure 7. Again, three main groups have been been characterised as follows:

- ***Light blue CL-Group*** includes IT Tools in Industrial Processes (CL3) and Manufacturing Automation and Robotics (CL4). This group is distinguished by a predominant use of IT tools, digital technologies, and computer-related disciplines in I4.0.
- ***Green CL-Group*** includes Manufacturing Processes (CL1) and Design of Machines and Products (CL2). This group contains more traditional engineer aspects for designing and developing the process and the product. Although digital data and computer-aided engineering (CAE) software packages are used in these disciplines, theoretical knowledge and the experimental approach are of paramount importance.
- ***Red CL-Group*** includes aspects of Production Planning and Control (CL5) and Logistics and Supply Chain Management (CL6). These aspects are primarily involved in managerial activities and take advantage of the cyber-physical integration of data in I4.0. For decision-making, a comprehensive overview of a product's production state or delivery state with real-time information is required.

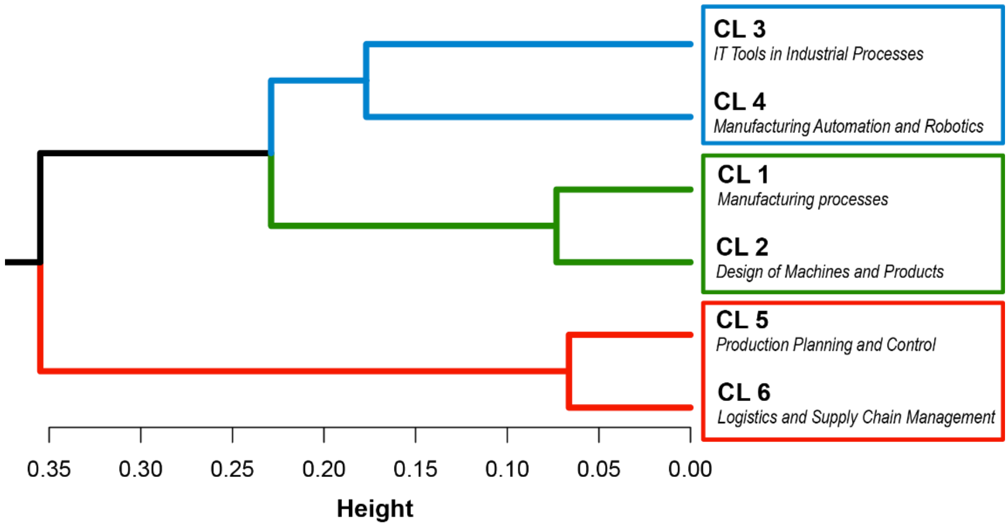

Figure 7: Hierarchical clustering of the six clusters of competences of the *industrial* engineer archetype.

The dendrogram in Figure 7 also shows that a further clustering reduces to two groups only: the technical aspects from CL1 to CL4 can be grouped separately from the managerial aspects CL5 and CL6.

Toward a Sustainable Engineer Archetype through Industry 4.0 Engineer

Authors: Anonymous

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Abstract

In the last decade, a shift toward sustainable developmentSustainable Development (SD) in engineering, both has started in the educational and occupational framework, has started.. Therefore, the need to rethink the professional figures of an engineer has become a necessity. Unfortunately, neither a formal methodology to define a standard engineer profile (hereinafter archetype) nor procedural methods to evaluate the impact of such archetypes on sustainabilityarchetypes' contribution to SD are investigated. This paper bridges these two gapsthe first gap by proposing a general methodology to define engineering archetype as a set of Industry 4.0 (I4.0) engineeringspecific engineer archetypes as technical competences and a procedural method to evaluate its sustainability. Toward educational and occupational frameworks, I4.0 competences are defined respectively from educational - Semi Structured Intended Learning Outcomes (SS-ILOs) and professional skills.- and occupational - European Skills, Competences, Qualifications and Occupations (ESCO)- frameworks. The sustainability evaluationsecond gap is addressed by a procedural method based on indirect mapping of the identified archetypes onto United Nations Sustainable Development Goals (UN-SDGs) through I4.0. To illustrate the). Since Industry 4.0 (I4.0) is related to engineer archetypes and SDGs, it is used as a bridge. Finally, we provide the application of our proposed approach, an industrial engineer archetype is defined, and its sustainability is assessed.methodology to the *Industrial* engineering case study. The result showsresults show that significant limitations toward sustainability remain open challenges. TheHowever, the intrinsic nature of the *industrial* engineer is confined to some specific goals, and a characteristic signature on sustainability clearly emerged.

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Keywords: *industry 4.0, engineer profile, sustainability, professional archetype, sustainable development, sustainable engineering, industrial engineering*

1 Introduction

Worldwide sustainable developmentSustainable Development (SD) is one of the most challenging as well asand exciting problems that humanity has ever faced. In the last decades, the uncontrolled anthropogenic impact on the three pillars of sustainability (economic, social, and environmental) caused and worsened many problems within and among countries [1]. It is most probably the major cause forof environmental degradation, climate change, and more frequent and intense natural disasters. It also exacerbates the majority of the problems that challenge having a fair life in thison our planet with dignity and tranquilitytranquillity. War, poverty, humanitarian crises, terrorism, migrations, enormous disparities of opportunities, and fragility and inequality of our healthcare systems are examples of these unresolved problems [2]–[4].[2]. On the other hand, this era has immense opportunities as well as responsibilities.

The 17 Sustainable Development Goals (SDGs) outlined by the United Nations (UN) call on contributions from all the society stakeholders, including local and national governments, non-governmental organisations, and individuals. This universally shared model finally offers the opportunity to address and face such urgent global issues by an integrated view. As described in the SDGs, engaging with sustainability-related problems requires a complete set of knowledge, skills, values, and attitudes which empower individuals to meet current and non-current needs without affecting the ability of future generations [3].

In the last decades, a shift toward SD affects policies, educational and occupational scenarios. The redefinition of the relevant learning objectives that empower learners in the construction of sustainability-related skills are moving toward the "right" direction, and Education for Sustainable Development (ESD) deserves particular merit [4]. Among many areas, engineering education has a potential role in generating a fundamental group of possible change agents that could highly and quickly impact the SDGs fulfilment by informed decisions and responsible actions [5]–[7]. Furthermore, the practical occupational framework can empower new engineers responsible for SD transition [8], [9]. In this framework, we aim to investigate "*How much does a specific engineer archetype contribute to SD?"*. However, clear procedures on how to define engineer archetypes (e.g., sets of features that characterise specific engineer types) is an open issue that has not received sufficient attention from the scientific community [14]–[16]. Only generic regulatory documents such as standards, certifications, accreditations, and national regulations have been drafted so far [10]–[13]. For this reason, as preparatory work, we aim to explore "*How to define the engineer archetypes?"*.

Thus, we will denote the latter question as Research Question 1 (**RQ1**) and the former as **RQ2** since the engineer archetype contribution to SD can be evaluated if an engineer archetype is defined beforehand. After this initial introduction, a more detailed analysis of the two research questions that triggered our work is reported in the following paragraphs.

RQ1: *How to define the* On the other side, this era has immense opportunities as well as responsibilities. The 17 Sustainable Development Goals (SDGs) outlined by the United Nations (UN) call on contributions from all the society stakeholders, including local and national governments, organization types, and individuals. *engineer archetypes?*

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Among others, formally defining a specific type of standard engineer is a crucial aspect that could affect many stakeholders in the educational (e.g., students, professors, universities as institutions) and occupational (e.g., placement services, private companies, public bodies) framework. To develop a general methodology for defining specific groups of engineers, we adopted the concept of abstraction. The main consequence of this abstraction is the definition of typical examples of a particular group of people, things or systems instances whose representative patterns are extracted and formalised in a metamodel, i.e., archetypes [17], [18]. A specific standard engineering archetype (e.g., *industrial* engineer, mechanical engineer, electrical engineer, management engineer) is thus identified as a set of theoretical/practical and actual competences. In more details, these competences, both generic and specific, can be retrieved from engineering educational programs and occupational engineering databases. Thus, program contents or syllabi could be claimed to "describe" a particular type of engineer from an educational perspective. Occupational databases, on the other hand, could offer up-to-date specific labour market related competences.

This universally shared model finally offers the opportunity to address and face such urgent global issues by an integrated view. Engaging with sustainability-related issues, as described in the SDGs, requires possessing a full set of knowledge, skills, values, and attitudes that empower individuals with the purpose of "*meeting currents needs without affecting the ability of the future generations"* [5]. In the last decades, a shift toward sustainable development affects policies, educational and occupational scenarios. The redefinition of the relevant learning objectives and learning contents as well as introduction of pedagogies that empower learners in the construction of sustainability related skills are moving toward the "right" direction [6]. Among many areas, engineering education has a potential role in generating a fundamental group of possible change agents that could highly and quickly impact the SDGs fulfillment by informed decisions and responsible actions [7], [8]. In parallel, the practical occupational framework can empower new engineer profiles that gain more responsibility in the sustainability trend transition.

As highlighted by Boucher et al. [9], the topical requirements for industrial systems have progressively reintroduced human skills, competences, or know-how as the main source of industrial performance. However, a significant restriction to the latter aspect is the usual association of soft skills (instead of hard competences) concerning sustainability [10], [11]. Unfortunately, we are not aware of a methodology that can help to define these engineering competences, which will be called herein engineer archetypes. The definition of a *standard* engineer archetype or at least a European engineer could help in the redefinition of the engineer profile both from an educational and occupational perspective and opens numerous applications. Moreover, a method to evaluate the sustainability of such archetypes is also missing; therefore, it is not possible to measure the progress in the transition toward sustainability, neither from an educational nor from an occupational perspective.

In this context, the ongoing research under the Erasmus+ Programme of the European Commission called "Manufacturing Education for a Sustainable Fourth Industrial Revolution" (MAESTRO) project [12], offers a fertilization environment of academic experts from diverse engineering disciplines such as industrial, mechanical, electrical, management and production as well sustainable education. The consortium was formed by seven teams from seven European higher education organizations from six European countries (Sweden, United Kingdom, Italy, Portugal, Poland, and Slovenia). They are putting efforts to define and deliver competences to prepare engineers to work in the I4.0 revolution and in a harmony with SDGs. In this challenging context, this paper aims to answer the following research questions:

RQ1: *How to define the* engineering archetypes?

RQ2: *How much* of the sustainability aspects are addressed in these archetypes?

For the first question, also interpretable as "does a *standard* engineer exist? or at least a European engineer has been defined?", a methodology to define engineer archetypes as a set of I4.0 competences is proposed. Both educational and occupational competences are thus considered to define comprehensive archetypes, providing a ground to define. I4.0 is the common factor among industry and academia that allows grouping of competences from educational units for academic and occupational learningframeworks in the same list. The main benefit of using actual syllabi from education programs and occupational information, in contrast to regulatory documents, is a specific representation of a particular class of engineers based on existing implementations.

Concerning the previously identified stakeholders, benefits and applications due to the definition of an engineer archetype relate to the following activities: evaluation (e.g., SD assessment treated in this work, see the **RQ2**), design (e.g., build or re-design a new program by using the archetype as de-facto baseline), comparison (e.g., compare the existing archetypes in contrast to national, international, and global benchmarks or monitoring trends over time adopting a standard view), and communication (e.g., using the archetype a short and clear manifesto for a specific engineering program).

Summarizing, a general methodology for the abstraction of archetypes as a set of Industry 4.0 (I4.0) related competences is proposed to address the second research question.

RQ2: *How much* To answer the second question, we took advantage of our previous work, which proposed a systematic investigation on the influence of the I4.0 technologies onto the UN SDGs [13]. As shown in Figure 1, the defined engineer archetype sustainability is evaluated by mapping the engineering (*educational* and *occupational*) *competences onto the 17 SDGs* indirectly by *I4.0 mapping*.

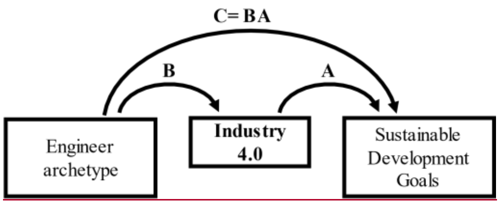

Figure 1: Arrow A represents our previous work [13] where I4.0 has been mapped onto SDGs and resulting in the matrix **A**. Mapping engineer archetype onto SDGs (arrow and matrix **C**) is therefore allowed using a preliminary mapping of the engineer archetype onto I4.0 (arrow and matrix **B**).

This paper is structured as follows*does a specific engineer archetype contribute to SD?*

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A need to assess professions for their contribution towards SD through the enabling technologies of I4.0 is an urgent topic. However, as reported by Stock et al. [19], current research shows that there is still a lack of method-based and quantitative investigations of sustainability impacts of I4.0 as well as of possible contribution to SD. Despite several methodologies on quantitative assessment of I4.0 technologies have been developed (e.g., [20], [21]), and rather significant literature on the sustainability assessment in the educational framework is available (e.g., [5], [22], [23]), a general methodology for the sustainability assessment of engineer archetypes still lacks. Our work is the first attempt at defining engineer archetype in literature, and consequently, its sustainability assessment is implicitly novel. Therefore, to answer the second research question, we propose an evaluation of the engineer archetype contributing to SD by mapping the engineer archetype onto the 17 SDGs indirectly by using I4.0 mapping, as shown in Figure 1. In the first step (arrow B in Figure 1) to connect engineer archetypes and I4.0, we adopted the method developed for the **RQ1**. In the second step (arrow A in Figure 1), we took advantage of our previous work, which proposed a systematic investigation of the influence of the I4.0 technologies onto the UN-SDGs to connect I4.0 to sustainability [24]. Finally, the use of I4.0 paradigm allows the connection of the technical competences characterising engineer archetypes to the sustainable dimension of the SDGs. Hence, the benefit of connecting I4.0 to the left and right side of Figure 1 is the possibility to map how much a specific engineer archetype contributes to SD providing an answer to the **RQ2**. For this reason, since I4.0 represents the core concept of the assessment step, the corresponding box in Figure 1 has been highlighted.

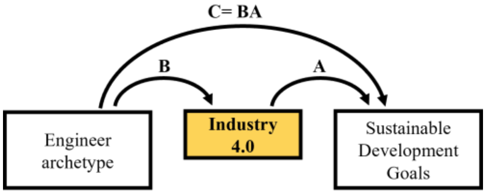

Figure 1: The steps to map the engineer archetype onto SDGs. Arrow **A** represents our previous work [24] where I4.0 has been mapped onto SDGs and resulting in the matrix **A**. Mapping engineer archetype onto SDGs (arrow and matrix **C**) is therefore allowed using a preliminary mapping of the engineer archetype onto I4.0 (arrow and matrix **B**) and using the matrix product.

The main results of this work are thereby i) an approach for defining engineer archetypes and ii) a methodology for assessing engineer archetypes contribution to sustainability.

This paper results from diverse engineering disciplines from seven European higher education organisations (Sweden, United Kingdom, Italy, Portugal, Poland, and Slovenia). A reminder of the structure is detailed here: a background along withand relevant literature isare presented in Section 2. Section 3 describes the methodology for defining engineeringengineer archetypes (**RQ1**) and the proposed method to evaluate the sustainability of the archetypes (**RQ2**). In Section 4, an illustrative application of the proposed method is presented for *industrial* engineers, addressing the two questions, and providing a deep analysis and interpretation of the results. TheFinally, the discussion and conclusion are presented in Sections 5 and 6, respectively.

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2 Background

This section discusses the research background of this work. It starts by providing an overview of UN-SDGs in section 2.1 and continue with a discussion of sustainability in engineering education in section 2.2 as well as in the occupational framework in section 2.3. Engineering is a major driver in industry and has a substantial effect on sustainability [13]. Section 2.4. discusses this influence, focusing on I4.0 as the dominant industrial future. It starts by providing an overview of UN-SDGs in section 2.1 and continues with a discussion of SD in engineering education and occupational framework in sections 2.2 and 2.3, respectively. Engineering is a significant development in industry and has a substantial effect on sustainability [24]. Section 2.4. discusses this effect, focusing on I4.0 as the dominant industrial paradigm. Finally, the I4.0 and SD relation is discussed in section 2.5.

2.1 Sustainable Development Goals (SDGs)

After ~~the development of~~developing prior Millennium Development Goals (MDGs), 193 worldwide governments met at the historic ~~United Nations~~UN Summit in September 2015 and agreed to the 17 SDGs and corresponding 169 targets ~~(Figure 2)~~ to draw the 2030 Agenda for ~~Sustainable Development~~SD ~~[14].~~[25]. "*The Goals and targets are the ~~result~~results of over two years of intensive public consultation and engagement with civil society and other stakeholders around the world, which paid particular attention to the voices of the poorest and most vulnerable. The SDGs and relatives' targets are integrated and indivisible, global in nature and universally applicable, considering different national realities and respecting national policies and priorities*" [2].

The extreme degree of complexity resulting from the integration and indivisibility of the 17 SDGs and relatives' targets can be justified by the nature of these goals. ~~As highlighted in the pyramid of UN sustainability objectives in Figure 2, the~~The SDGs and targets have been derived using a top-down approach by focusing on sustainability as the highest target for people, the planet, and prosperity, reflecting ~~what~~ the 2030 Agenda commitment for ~~Sustainable Development is looking for~~SD. A holistic perspective sees the concept of sustainability as a dynamic and evolving combination of ~~contextual~~ interconnected contextual variables (social, economic, and environmental) with temporal considerations (short, medium, and long-term) ~~[15]. The integration and indivisibility of these three pillars reflects in the second level characterized~~[26]. The integration and indivisibility of these three pillars reflect in the second level, characterised by a set of interconnected challenging visions (i.e., goals) whose achievement can lead to sustainability. Each goal typically has 8–12 targets, and each target has 1–4 indicators to measure the progress toward reaching the targets. Therefore, the third level represents ~~the deployment of~~ 169 specific targets for 17 goals, ~~which inherits~~inheriting the integration and indivisibility defined at the root.

~~**Figure 2:** The pyramid of UN sustainability objectives deployment [14].~~

Table 1 provides a short description of the 17 SDGs, along with the goals' acronyms and graph legend, which will be referred to in the paper remainder. ~~Huge~~Tremendous opportunities could be gained based on the SDGs synergies and benefits, cutting down their trade-off. Since the announcement of the SDGs, a growing interest is dedicated to ~~investigate~~investigating SDGs related aspects, including indicators for goals integrations ~~[16]~~[27], achievement assessment ~~[17]~~[28], energy-related targets ~~[18]~~[29], planet impacts ~~[16]~~[27], Artificial Intelligence (AI) role ~~[19]–[21]~~[30]–[32], coping with the consequences of economic systems ~~[22]~~[33], and the influence of the I4.0 on the goals [~~13~~24].

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~~**Table 1:** Description of the Sustainable Development Goals (Adapted from [14]).~~

Table 1: Description of the Sustainable Development Goals (Adapted from [25]).

Sustainable Development Goal (SDG)	Short Description	Graph legend
SDG1: No Poverty	End poverty in all its forms everywhere	
SDG2: Zero Hunger	End hunger, achieve food security and improved nutrition as well as promote sustainable agriculture	
SDG3: Good Health and Well-being	Ensure healthy live and promote well-being for all at all ages	
SDG4: Quality Education	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	
SDG5: Gender Equality	Achieve gender equality by providing equal opportunities for both genders	
SDG6: Clean Water and Sanitation	Ensure availability and efficient management of water and sanitation for all	
SDG7: Affordable and Clean Energy	Ensure access to affordable, reliable, and ecofriendly energy for all	
SDG8: Decent Work and Economic Growth	Promote inclusive economic growth, full and productive employment, and decent work for all	
SDG9: Industry, Innovation, and Infrastructure	Build resilient infrastructure, promote inclusive and eco-friendly ~~industrialization~~industrialisation and foster innovation	
SDG10: Reduced Inequality	Reduce inequality within and among countries	
SDG11: Sustainable Cities and Communities	Make cities and human settlements inclusive, safe, resilient, and eco-friendly	
SDG12: Responsible Consumption and Production	Ensure reasonable and efficient consumption and production patterns	
SDG13: Climate Action	Take urgent action to combat climate change and its impacts	
SDG14: Life Below Water	Considerable consumption and usage of oceans, seas, and marine resources that preserve the for future generations	
SDG15: Life on Land	Protect, restore, and promote responsible use of terrestrial ecosystems and forests, combat desertification, and halt and reverse land degradation and biodiversity losses	
SDG16: Peace and Justice Strong Institutions	Promote peaceful and inclusive societies, provide access to justice for all and build effective, accountable, and inclusive institutions at all levels	
SDG17: Partnerships to achieve the Goal	Strengthen the means to implement and ~~revitalize~~revitalise the global partnership for sustainable development	

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2.2 ~~Sustainability~~Sustainable Development (SD) in the engineering educational framework

The Sustainable Agenda ~~dedicates~~denotes SDG4: Quality Education as a standalone goal to achieve sustainable education and at the same time as a key enabler in the pursuit of all the remaining 16 SDGs. In this manner, education is viewed as an engine for change ~~by means of a~~through lifelong learning ranging from formal (preschool to tertiary and adult education) to informal education (online courses and self-education) ~~[6]. Education for SDGs (ESD) promoted by the United Nations Educational, Scientific and Cultural~~

Organization (UNESCO)[4]. Education for Sustainable Development (ESD), promoted by the United Nations Educational, Scientific and Cultural Organization (UNESCO), guides education professionals to contribute toward the SDGs achievement [6]. Within the past generation, hundreds of millions of people have emerged from extreme poverty and the access to education has greatly[4]. Nowadays, hundreds of millions of people have emerged from extreme poverty within the past generation, and access to education has dramatically increased [2]. However, unfortunately, industrializedindustrialised countries often prepare students for their competitive participation in the global economy rather than becoming critical and responsible members of society [1526].

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In the evolution of the classical paradigm of the engineer archetypes, considerable efforts have been dedicated to the realignment of the educational provision to the modern challenges toward engineers contributing to SD [7], [34], [35]. However, as Leifler et al. [5] concluded in their recent study according to Swedish engineering universities and directors of engineering colleges, deep integration of sustainability into the core subjects is lacking. As a result, the progression of sustainability through programs is often weak. Furthermore, the lack of impact of the engineering curricula on specific SDGs, e.g., SDG10, SDG16, and SDG17, have been also highlighted [5]. Such limitations call for studies and approaches that facilitate the design and implementation of educational content which comply with SDGs [36]. However, interpretation of the SDGs in courses design is a complicated process. A valuable enabler that could help in this transition is the formalisation offered by the Constructive Alignment (CA) framework that focuses on the alignment of Intended Learning Outcomes (ILOs), Teaching and Learning Activities (TLAs) as well as Assessment Tasks (ATs) [37].

Accreditation bodies (i.e., The Engineering Accreditation Board (EAB) in the United Kingdom [13], the European Network for Accreditation of Engineering Education (ENAEE) in Europe [12], and the Accreditation Board for Engineering and Technology (ABET) in the United States [11]) have developed their standards covering SD to some extent. As highlighted by recent initiatives, these accreditation bodies and UNESCO are pushing toward establishing a new paradigm for the professional figure of an engineer as a true enabler, equaliser, and accelerator to deliver the SDGs [38]. However, despite numerous guidelines and standards on ESD (e.g., [39]–[41]), an objective understanding of how much a specific engineering archetype contribute to the SDGs is still unesxplored. We only have to assess the achievement of learning outcomes at one point in time at one's disposal, thereby neglecting the actual learning process [5]. Additional works that evaluate the integration of sustainability in higher education [22] and national frameworks for assessing sustainability integration [23] are still far from our aim.

2.3 Sustainable Development (SD) in the occupational engineering framework

As the main result of the education process, the practice of making everyday decisions in occupational and job-related scenarios defines the real impact of engineers on economic, social, and environmental issues [33], [34]. Furthermore, the peculiar huge set of hard skills owned by these practitioners define the related responsibilities for the innovative job ecosystem that account for SD [42]. This aspect of the relationship between technology and sustainability trends determine the critical role of engineers as professional figures that could quickly deliver high impact on SD, as highlighted in [6], [43], [44].

Thus, this influence of technological revolutions toward sustainability highlights the need for professional skills transformation, especially in engineering occupations, which are the ground to foster and realise SD revolutions [42]. As highlighted by Boucher et al. In the evolution of the classical paradigm of the engineer profile, a considerable efforts have been dedicated to the realignment of the educational provision to the modern challenges toward a "Sustainable Engineer" [23]–[25]. As for the course design, teachers have been challenged to comply with Constructive Alignment (CA) approach that focuses on the alignment of Intended Learning Outcome (ILO) to the Teaching and Learning Activities (TLA) as well as Assessment Task (AT) [26]. By focusing into the ILOs, they use sentences providing acting verbs, contents, and contexts that mainly cover what the students should be able to do at the end of the course. Interpret SDGs in defining these educational units is a complicated process. Leifler et al. [8] concluded in their recent study that, according to Swedish engineering universities and directors of engineering colleges, deep integration of sustainability into the core subjects are lacking and the progression of sustainability through programs is often weak. The lack of impact of the engineering curricula on specific SDGs, e.g., SDG10, SDG16 and SDG17 have been also highlighted [8]. Such limitations call for studies and approaches that facilitate the design and implementation of educational unit that comply with SDGs [27].

Accreditation bodies (i.e., The Engineering Accreditation Board (EAB) in the UK [28], the European Network for Accreditation of Engineering Education (ENAEE) in Europe [29], and the Accreditation Board for Engineering and Technology (ABET) in the US [30]) have developed their own standards and sustainability has been covered to some extent. As highlighted by recent initiatives, these accreditation bodies together with UNESCO are still pushing toward the establishment of a new paradigms for the professional figure of engineer as a true enabler, equalizer, and accelerator to deliver the SDGs [31]. However, despite numerous guidelines and standards on teaching the SDGs (e.g., [32]-[34]) and the above mentioned initiatives, an objective understanding on how much a specific engineering professional is aligned with the SDGs is missing.

2.3 Sustainability in the engineering occupational framework

As the main result from the education process, the practice of making everyday decisions in occupational scenarios defines the real impact on economic, social, and environmental issues [22], [23]. The peculiar huge set of hard skills owned by engineers define the related responsibilities in making such decisions [35]. This aspect of the relationship between technology and qualification development trends determines the role of educational organizations into innovative ecosystems.

The influence of technological revolutions toward sustainability highlights the need for professional skills transformation, especially in engineering occupations, which are the ground to foster and realize revolutions [35]. Indeed, the multilingual classification of European Skills, Competences, Occupations and Qualifications (ESCO) database deserves significant attention when describing, identifying, and classifying professional occupations and skills that should be gained by the end of a specific qualification (e.g., *industrial* engineer) [36]. The European Commission developed ESCO to map the existing "occupational profiles" in Europe for 27 sectors of the economy in July 2017. These diverse sectors are taken from the statistical classification of economic activities in the European Community or NACE [37]. In August 2020, a new version had been published, which remains a trending tool for both employers and education programs designers, in academia and in lifelong learning, offering updated information on the new trending skills, and it systematically shows the semantic relationships between different skills [36].

From the industrial organizations side, numerous aspects are highly important in Health, Safety and Environment (HSE) as well as sustainable systems [38], [39]. However, managing change toward sustainability is far from being simple and a clear and compact definition of what an engineer is and how it could be associated with sustainability are missing. Therefore, define engineer archetypes are helpful to be a ground to design practical skills and pedagogical units and harmonize it with the SDGs. To define archetypes, designers of occupational and academic programs must consider overwhelming requirements, spanning from governmental and accreditation body standards to technologies advancements and sustainable agenda. A systematic approach for meeting these multidimensional requirements in defining archetypes is needed.

2.4 Industry 4.0 and engineering

Industry 4.0 (I4.0) is a well-known vision that describes the introduction and implementation of new technological concepts to fully interconnect production elements by bridging the physical and digital world [40], [41]. The integration of Information Communication Technologies (ICT) and industrial technology lead to the creation of a cyber-physical system to realize an intelligent factory promoting more digital, highly flexible, and green production model [42], [43]. Another important purpose of this new vision is to build systems with real-time interactions between people, products and devices [44]. Classical engineering domains such as manufacturing, informatics, and process technologies deserve significant attention in the rethinking of merging interdisciplinary knowledge together with industry 4.0 enabling technologies [41], [45].[45], the topical requirements for industrial systems have progressively reintroduced human skills, competences, or know-how as the primary source of industrial performance. However, a significant restriction to the latter aspects is the usual association of soft skills (instead of complex competences) concerning SD and a real marginal commitment from the top management [15], [46].

Indeed, the multilingual classification of European Skills, Competences, Occupations and Qualifications (ESCO) database deserves significant attention when describing, identifying, and classifying actual and up-to-date professional skills that should be gained by the end of a specific qualification (e.g., *industrial* engineer) [47]. The European Commission developed ESCO to map the existing "occupational profiles" in Europe for 27 economic sectors in July 2017. These diverse sectors are taken from the statistical classification of economic activities in the European Community (NACE) [48]. In August 2020, a new version of ESCO was released. It remains a trending tool for both employers and education programs designers in academia and lifelong learning, offering updated information on the new trending skills and systematically showing the semantic relationships between different skills [47].

To define engineers' archetypes, experts of occupational and academic programs must consider overwhelming engineers' competences, spanning from academia to the labour market. By querying the ESCO database, a systematic approach for the latter can be drafted.

2.4 Industry 4.0 (I4.0) and engineering

I4.0 is a well-known vision that describes the introduction and implementation of new technological concepts to fully interconnect production elements by bridging the physical and digital worlds [49], [50]. The integration of Information Communication Technologies (ICT) and industrial technology lead to the creation of a Cyber-Physical System (CPS) to accomplish an intelligent factory promoting a more digital, highly flexible, and green production model [51], [52]. Another essential purpose of this new vision is to build systems with real-time interactions between people, products and devices [53]. Classical engineering domains such as manufacturing, management, informatics, and process technologies deserve significant attention in the rethinking of merging interdisciplinary knowledge with I4.0 enabling technologies [50], [54]. In this framework, our recent paper defined a detailed list of 44 I4.0 technology elements (i.e., E1.1_E9.2) derived from nine well known I4.0 enablers (i.e., E1-E9) [24]. Table 2 summarises a clear definition of the nine enablers [55]–[57] at a lower granularity level to facilitate the technologies' interpretation in the further steps of this work.

Table 2: I4.0 enablers and the technology elements (or subenablers) [24].

As highlighted by Ramirez-Mendoza et. al. [44], several efforts have been detonated in the world trying to better understand the evolution in the engineering education toward the I4.0 and numerous frameworks for the definition of new curricula for I4.0 in engineering education have been proposed. Example of such work are reported in the following papers: [41], [44], [46]. However, the lack of a systematic and comprehensive procedure for the definition of standard engineer that encompasses both old and new I4.0 competences focusing on sustainability impact is still an open issue.

To revolutionize engineering contents with I4.0 technologies, a clear definition of these technologies at a lower granularity level is essential, which facilitates the interpretation of the technologies and include it in such contents. Toward this end, our recent paper [13] systematically defined I4.0 elements technologies at a sufficient granularity level. Table 2 shows the defined technologies at two levels: called enablers (i.e., E1) and element technologies (i.e., E1.1). The paper also is the first attempts to comprehensively quantify the influence of I4.0 technologies on the 17 sustainability goals. It shows the technologies that are believed to have a substantial effect toward the SDGs achievement. Such promising technologies should be prioritized and considered in teaching future engineers. However, an effort is needed to transform the emerging I4.0

technologies into engineering competences. Also harmonizing such transformation with SDGs is still an open challenge.

Table 2: I4.0 enablers and the element technologies (subenablers) [13].

Enablers	~~Element technologies~~ Technology elements
E1 Industrial Internet of Things	E1.1 General Identification E1.2 Ubiquitous Sensing E1.3 Seamless and Real-Time Communication E1.4 Embedded & Edge Computation E1.5 Services Oriented Architecture (SOA) E1.6 Interoperable Semantics Communication
E2 Big Data & analytics	E2.1 Sensors E2.2 Data collecting E2.3 Data processing E2.4 Data querying E2.5 Data access E2.6 Data analytics E2.7 Decision-making support E2.8 Data management techniques and methods
E3 Cloud Computing	E3.1 Computing E3.2 Interoperability E3.3 Servicelisation (on the Cloud) E3.4 Cloud Manufacturing
E4 Simulation	E4.1 Products and processes E4.2 Production lines, workstations, and internal logistics E4.3 Enterprise and its operational environment
E5 Augmented Reality	E5.1 Machine interaction E5.2 Human interaction E5.3 Training E5.4 Communication E5.5 Simulation
E6 Additive Manufacturing (AM)	E6.1 Processes for polymers E6.2 Processes for metals E6.3 Processes for ceramics E6.4 Materials E6.5 Design for ~~AM~~Additive Manufacturing E6.6 Software
E7 Horizontal & Vertical System Integration	E7.1 Reference Architecture E7.2 Reference Architecture Model I4.0 (RAMI 4.0) E7.3 Systems Integration E7.4 Digital Twins E7.5 Cyber Physical System E7.6 System of Systems E7.7 Collaborative Networks
E8 Autonomous Robots	E8.1 Perception E8.2 Deliberation E8.3 Autonomy
E9 Cybersecurity	E9.1 Threat identification and detection E9.2 Data loss prevention

As highlighted by Ramirez-Mendoza et al. [53], several efforts have been detonated in the world trying to better understand the evolution in engineering education toward the I4.0, and numerous frameworks for defining new curricula for I4.0 in engineering education have been proposed. Example of such work are reported in the following references: [58], [50], [53], [59]. However, the lack of a systematic and comprehensive procedure for the definition of standard archetype engineer that encompasses both old and new I4.0 competences is still an open issue.

2.5 Industry 4.0 (I4.0) and Sustainable Development (SD)

I4.0 and SD are considered significant trends in the current production system since the former has the unique potential to unlock the latter. Through their synergy, they may together comprise a distinct industrial wave that will change worldwide production systems forever [20].

The rapidly growing interest in the interplay between I4.0 and sustainability from both academia and industry is a fact. In the scientific literature, for instance, please refer to [60]–[64]. As for recent national and international manoeuvres, investments in infrastructure and advanced technological setups or drawing of new standards and regulations, please see, for example, [65]–[67]. This work itself is part of the European Commission Erasmus+ Programme project named “Manufacturing Education for a Sustainable Fourth Industrial Revolution” (MAESTRO) [69].

Within the same framework, our previous paper [24] defines the technology elements but mostly is the first attempt to comprehensively quantify the influence of these I4.0 technology elements on the 17 SDGs. This influence is explicitly stated in the eighth targets of *SDG9: industry, innovation, and infrastructure*, and can be implicitly deduced from the majority of the other 161 targets. Since SDGs aim to provide a blueprint for peace and prosperity for humanity and the earth, the influences of the I4.0 technologies are not equal for all these goals. While the impact is significant and straightforward for some goals, it is minor and indirect on others [24]. The sustainable influence of the I4.0 technologies by mapping these technologies to the SDGs has been identified using a consensus-based quantitative assessment. The output is matrix **A** and itcan be found in Appendix 1, Table 4.

Even though promising technologies should be prioritised and considered in teaching future engineers, an effort is needed to connect the emerging I4.0 technologies into engineering competences. Also, harmonising such transformation with SDGs is still an open gap that the proposed work aims to fill.

3 Methodology

This section provides a detailed description of the suggested methodology to address the two research questions: **RQ1** and **RQ2**. Figure ~~3~~2 depicts the theory behind this methodology. ~~To address **RQ1**, a~~A procedural method to define archetypes is suggested~~.~~ to address **RQ1**~~,~~. The ~~raw~~basic information for educational learning outcomes and occupational skills are retrieved from university programs and ~~from~~ the ESCO database, respectively, as discussed in section 3.1 (Figure ~~3~~2, left). Once the archetype has been defined, assessing the sustainability of the defined archetypes (**RQ2**) is the next step. As the direct relation between archetypes and SDGs ~~are difficult~~is challenging to ~~be investigated~~investigate, an indirect quantification of the ~~relation~~connection of the archetypes and SDGs through the I4.0 technology is proposed in section 3.2 (Figure ~~3~~2, right). We provide the *industrial* engineering case study for a practical application and procedural hints and lessons learned (section 4).

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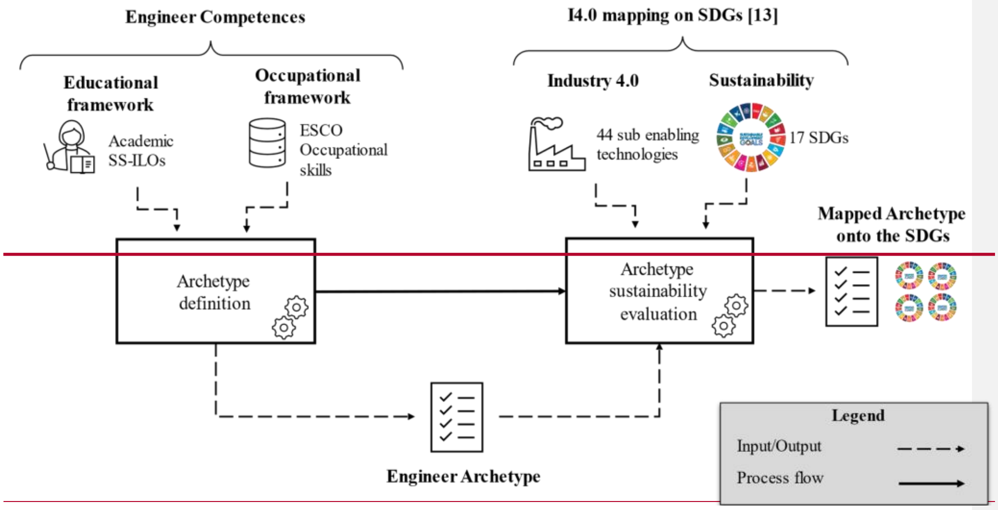

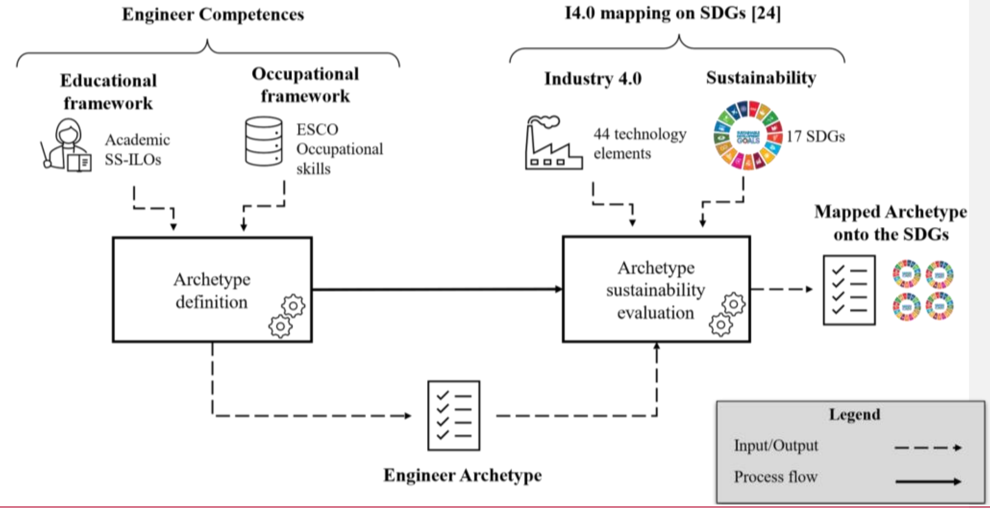

Figure 32: Flowchart of the proposed methodology to define a standard engineer profile (archetype) and assess its sustainability, through the I4.0 subenablerstechnology elements.

3.1 Archetype definition

As anticipatedmentioned in the introduction (section1) and background (section 2.,), standard engineer archetypes have not yet been defined norneither in the educational (section 2.2) neithernor in the occupational (section 2.3) frameworks. To answer **RQ1,** a method to provide the procedural steps for designers of learning frameworks is detailed. This guidance method helps to systematically define standard engineer archetypes inthrough a systematic way.collaborative working group. The following two types of engineering competences are used (Figure 3, left)adopted as input raw data: (Figure 2, left):

I. ***Academic SS-ILOs*** are sets of Semi Structured Intended Learning OutcomeOutcomes derived from the related courses insyllabi of the universityuniversities program under interest. Semi

Structured ILOs are a less formal version of the well-established ILOs To maximise the number of SS-ILOs that are used to overcome different degrees of formalization from diverse academic institutions. characterise the archetype, we suggest accounting for all (generic and specific) master's degree courses. Basic knowledge such as math, physics, and other bachelor engineering competences are implicitly embedded in any engineer and less relevant in the characterisation of a specific engineer archetype. From a practical side, a general guideline for construct the SS-ILOs is given as follow:

An ideal number of courses cannot be drafted generally. It depends on the amount of effort in extracting such information and processing time for subsequent activities. However, it is evident that the more courses are offered, the more accurate will be the final archetype. Based on experience, we believe that about 50 courses are sufficient since more extensive sets duplicate the data.

I. Given a specific course, the SS-ILOs represent a set of sentences (- from two to five, - depending on the number of delivered topics, recappable with the number of /credits). They are a sort of abstract with the main, which sum up the primary purposes and intended outcomes that athe course should achieve. For a specific course, we suggest i)relying on the three pillars of ILOs (i.e., acting verbs, contents, and contexts), ii)focusing on what the students should be able to do at the end of the course, and iii) using from 10 to 25 words [35]. However, since the SS-ILOs are "semi structured," these three pillars' presence is not mandatory. In contrast to the high degree of formality of the well-established ILOs, this solution overcomes different degrees of formalisation from diverse academic institutions. It maximises the generation of information without significant effort, even for those having no experience in CA. Examples are provided in Section 4.1 at step I.

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II. ***ESCO Occupational skills*** are a set of skills that characterizecharacterise the engineering profilearchetype under interest obtained from the ESCO database. As highlighted in section 2.3, this database offers a formal and multilingual classification for the main professions' skills. European professions' skills. Given a specific job, the related skills can automatically be retrieved in the database. Compared to SS-ILOs, this information set presents much more synthetic competences that often embed verbs and contents of the competence itself. Examples are provided in Section 4.1 at step II.

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The elements of the two sets are thus grouped, and an initial long list of competences is obtained. After this stage, the competences are clustered through a consensus-based approach by groups of academic experts. The aim is to define the final archetypes. The consensus-based approach, which is carried out following using the structured techniques to guide the working group.instructions presented in the next paragraph.

The main task of this activity is the synthesis of the input list to a final set of 5-10 clusters of competences that cover all the identified aspects. The engineer archetype is defined by the respective clusters of competences. hence define the engineer archetype. Duplicated or overlapping courses are to be merged in a fictitious meta course that extracts the main common patterns from diverse instances (e.g., similar courses from different institutions), minimising the information only to the necessary and sufficient. The output of this abstraction is, therefore, a consensus archetype made by a number (e.g., 5<x<10) of synthetic competence clusters denoted as CL1-CLx. An example that allow relatively easy management for further processing (see section 3.2). For additional information, the *industrial* engineering case study will be archetype example is presented in section 4 and is available in Table 3.

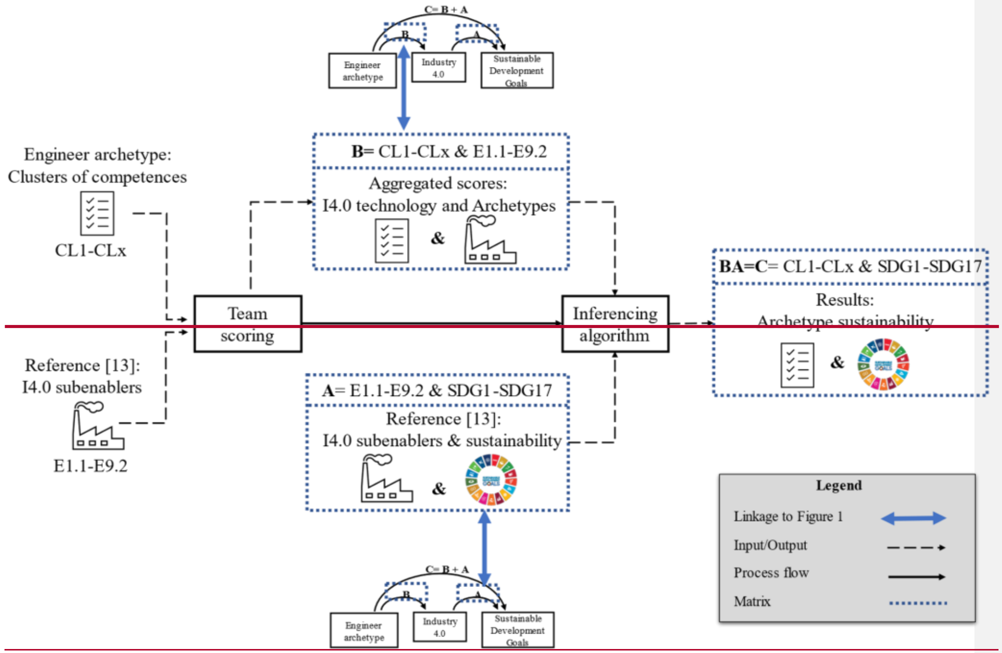
~~3.2 Archetype sustainability evaluation~~

~~This section describes the suggested method to assess the sustainability of an archetype as defined in section 3.1 and answers the second research question (**RQ2**). The relation between the archetypes and SDGs is complicated and cannot be assessed in a straightforward way. As anticipated, the suggested method indirectly exploits the result of mapping the I4.0 technology into the SDGs in [13]. As shown in Figure 4, once the archetype has been defined, the assessment is done in two consecutive steps:~~

3.2 Evaluation of the engineer archetype contribution to Sustainable Development (SD)

This section describes the suggested method to assess the sustainability of an engineer archetype as defined in section 3.1 and answers the second research question (**RQ2**). The relation between the archetypes and SDGs is complicated and cannot be assessed straightforwardly. Therefore, the assessment is regarding the competences of a specific type of engineer with respect to I4.0 technologies indirectly exploiting the result of mapping the I4.0 technology elements into the SDGs as detailed in [24] and summarised in section 2.5. As shown in Figure 3, the archetype and its contribution to each SDG passing through I4.0 technology elements are summarised by the **A** matrix having E1.1-E9.2 rows and SDG1-SDG17 columns. The assessment is done in two consecutive steps:

I. The ***team scoring*** activity involves ~~in the assessment of~~assessing the I4.0 ~~technologies~~technology elements consideration in the archetypes (Figure ~~4~~3, left). ~~The representation of~~First, the I4.0 ~~subenablers~~technology elements (Table 2) in the archetype ~~has been~~is evaluated by a panel of experts. ~~Each~~Then, each member of the panel ~~has assigned~~assigns a score for each cluster of competences (CL1-CLx), identified in the previous step~~,~~ (section 3.1), into the 44 ~~element technologies~~ technology elements (E1.1-E9.2). A four ordinal correlation measure is used: no correlation, weak, high, and very high correlation~~. The~~ that correspond to four possible ~~correlation~~ scores ~~are~~ 0, 1, 3 and 9~~;~~, respectevely; then, the average values from the panel of experts are computed. The result obtained is the **B** matrix having CL1-CLx rows and E1.1.-E9.2 column.



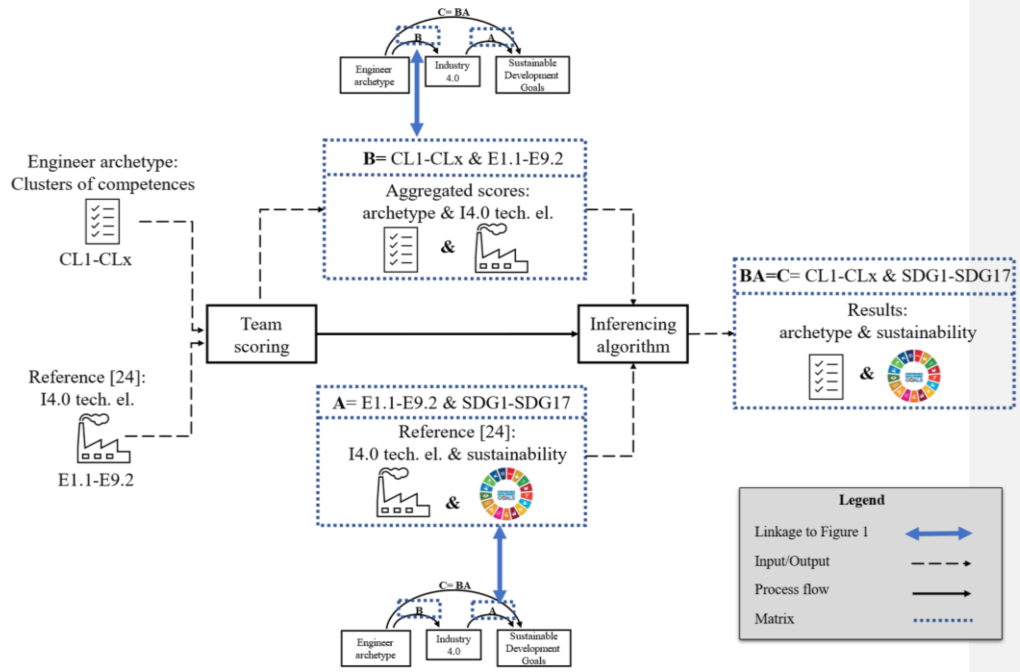


Figure 43: Outline of the proposed method for the sustainability evaluation of the engineer archetype.

~~II. The ***inferencing algorithm*** is based on the matrix product **BA**. As introduced in Figure 1, also represented as graphical item in Figure 4, the bridge that links archetype and sustainability is I4.0. Since the two matrices **B** = CL1-CLx & E1.1.-E9.2 and **A** = E1.1- E9.2 & SDG1-SDG12 share the I4.0 subenablers dimension, E1.1-E9.2, an algebraic product operator can be used. The inferencing algorithm used the team scoring result (matrix **B** in Figure 4) to deduce the sustainability relation via the mapping result in [13] (matrix **A** in Figure 4) and obtaining the final matrix **C=BA** that bridges the CLx (archetype) to each of the 17 SDGs (sustainability), where each element **C(*i,j*)** is the weighted average of the products as recalled in Algorithm 1.~~

II. The ***inferencing algorithm*** is based on the well-known matrix product that works for those matrices that share the same number of rows and columns. The only alteration is to compute a weighted mean, instead of the classical summation, for each output element of the final matrix. As introduced and highlighted in Figure 1, represented as a graphical item in Figure 3, the bridge that links archetype and sustainability is I4.0. Since the two matrices **B** = CL1-CLx & E1.1.-E9.2 and **A** = E1.1- E9.2 & SDG1-SDG12 share the I4.0 technology elements dimension (i.e., E1.1-E9.2), an algebraic product operator can be used. The inferencing algorithm used the team scoring result (matrix **B** in Figure 3) to deduce the sustainability relation via the mapping result in [24] (matrix **A** in Figure 3). The final matrix **C=BA=** CL1-CLx & SDG1-SDG17 thus bridges the CL1-CLx (i.e., the engineer archetype) to each of the 17 SDGs. Each element **C***i,j* is the weighted average of the products as recalled in Algorithm 1.

For a visual representation of the **A**, **B** and **C** matrices computed in the *industrial* engineer case study presented in section 4, please see the related Appendix 1.

Algorithm 1: Pseudocode ~~of~~used in the inferencing algorithm that indirectly ~~deduce the sustainability of archetypes.~~deduces the engineer archetype contribution to SD by computing the weighted average product of the matrices **B** and **A,** resulting in the matrix **C**

```
for each column_j where j=1 to X [or CL1-CLx]
      for each column_k where k=1 to 17 [or SDG1-SDG17]
           for each row_i where i=1 to 44 [or E1.1-E9.2]
                 sum1=sum1 + (cell_j,i * cell_k B_j,i * A_k,i)
                 sum2= sum2 + (cell_j B_j,i)
           end
           The CLj impact onto SDG_k-8 is computed as the
           weighted mean, thus C_j,k = sum1/sum2
      end
     plot the CLj radar diagramsdiagram by using C_j values
end
```

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4 *Industrial* engineer archetype case study

This section illustrates the application of the suggested approach ~~to a specific engineer archetype by defining an *industrial* engineer archetype and evaluating its sustainability. *Industrial*~~ for *industrial* engineering ~~can be dated back after the second Word War II and~~that can be positioned among mechanical, management and production engineering. ~~The application of the~~ A careful reading of this section could provide valuable and practical hints as well as good practices and lessons learned discovered during the actual application of the theoretical method proposed in section 3.

As a preparatory activity, the working group needed to be defined. In this case, a total of about 15 experts on *industrial* engineering (professors, PhDs, and researchers) from the seven academic institutions inside the MAESTRO project have been involved. We noticed that a reasonable lower bound could be at least three institutions, each providing from one to three experts.

Applying the two steps of the methodology described in ~~section~~sections 3.1 and 3.2 is ~~described in~~ used to define an industrial engineer archetype (section 4.1~~ and~~) and evaluate its contribution to SD (section 4.2~~,~~

respectively. Section). Finally, section 4.3 discusses the resulting sustainability evaluation and addresses improvement proposals as well as practical implications.

4.1 *Industrial* engineer archetype definition

An *industrial* engineer archetype has been defined from educational and occupational competences as follows:

I. A set of more than 100 SS-ILOs has been collected from more than 50 courses from master's degree programs in *industrial* engineering. The list of the SS-ILOs has been derived from the seven universities involved in the MAESTRO Project [12]. Basic knowledge such as math, physics, and bachelor *industrial* engineering competencies are implicitly embedded. distributed from seven European institutions involved in the MAESTRO project (e.g., Advanced Computer-Aided Design (CAD)/ Computer-Aided Manufacturing (CAM) programming, Rapid Prototyping, Advanced Manufacturing Technology, Metrology, Applied Computer Science, Assembly Technology, Automation and robotics, Classical Manufacturing Technology, Computerized Numerical Control (CNC), Design of machines and structure, Digital Factories, Fundamentals of electronics, Industrial plants, production planning and control, Integrated manufacturing systems, Lean manufacturing, Logistics & Supply Chain Management, Machines design, Mechanical materials, Modelling and Simulation of Industrial Processes, Non-conventional manufacturing techniques, Product Lifecycle Management, Quality Control, Recycling).

   The examples of derived SS-ILOs from the syllabus of the Non-conventional manufacturing techniques course are:

   - Analyse advanced additive manufacturing processes, water jet, laser cutting, industrial adhesive bonding and their potentials for new opportunities.
   - Use the full functionality of an advanced CAD modelling software of parts with complex shapes for rapid prototyping.

II. A set of more than 200 occupational skills from the ESCO database for the "*industrial* engineer" profilearchetype (ESCO Code 2141.3.) has been built. For clarity, a subset is reported here: use CAD software, use CAM software, use technical documentation, use thermal analysis provide cost-benefit analysis reports, read engineering drawings, monitor manufacturing quality standards, monitor production developments, evaluate engine performance, examine engineering principles, execute analytical mathematical calculations, execute feasibility study, develop product design, develop software prototype, analyse test data, etc.

This listing of more than 300 competences has(100 SS-ILOs + 200 occupational skills) have been further processed by the team members individually and collectively by virtualduring the online meetings. About 50 duplicate entries have been removed. The remaining competences have been merged to the compact set in the second column of Table 3. A further merging iteration has achieved a manageable number of clusters of competences: CL1-CL6 in the first column of Table 3. Table 3 represents a first attempt in the definition of a standard *industrial* engineer profilearchetype: CL1 is related to both conventional and non-conventional manufacturing processes, including assembly, as well as shop floor design and operations. CL2 is related to structures, machines, and products design, including software, simulations, analyses, experiments, and product data. CL3 focuses on software tools for digital manufacturing. CL4 is related to robotics and automation in general, including sensors, control theory and electronics. CL5 includes production planning and control, maintenance, Health, Safety and Environment (HSE) standards, statistical tools, and system optimizationoptimisation. CL6 is related to the supply chain/network management, including mathematical modelling and managerial topics, financial and economic aspects.

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Table 3: The *industrial* engineer archetype and its clusters of competences.

Clusters of competences	Summary of Competences
CL1: Manufacturing Processes	- Design and ~~analyze~~analyse a plan or specification for ~~the design of~~designing conventional industrial production systems (e.g., cutting, ~~molding~~moulding, deformation, welding~~ etc.).~~). - Design and ~~analyze nonconventional~~analyse non-conventional processes (e.g., advanced additive manufacturing, water jet, laser cutting, industrial adhesive bonding ~~etc.).~~). - Design and ~~analyze~~analyse the best-suited assembly technology, applying technical and economic criteria. - Use specific software for event-driven flow simulation to develop a balanced manufacturing flow within a factory. - Use specific software to develop factory layouts with buildings, manufacturing/assembly systems and factory assets.
CL2: Structures, Machines, and Products Design	- Research on and design ~~of~~for machines and mechanical installations, components, or testing prototypes using Computer Aided Engineering (CAE) tools. - Prepare drawing and technical documentation by applying standards and engineering principles. - ~~Analyze~~Analyse materials' ability to endure stress imposed by temperature, loads, motion, vibration, and other factors using mathematical formulae and simulations. - Conduct research and experiments.
CL3: Production IT Tools Infrastructure	- Practical skills in using CAE software for integrated manufacturing systems (e.g., CAD-Computer Aided Process Planning (CAPP~~-~~)-CAM). - Evaluate and Select optimal ~~IT~~ICT solutions to integrate with hardware systems. - Compare and assess ICT products and ~~service in terms of~~services regarding quality, costs, and compliance to specifications. - Design/Select ~~of~~ an optimal Product Lifecycle Management (PLM) system for product data control.
CL4: Manufacturing Automation and Robotics	- Apply robot modelling and control theory in robotic stations as well as design and build manufacturing systems. - Select suitable components, control systems and communication technology for automation of material handling and automated assembly. - Assemble robotic machines, devices, and components according to engineering drawings. - Program and install the necessary components of robotic systems, such as robot controllers, conveyors, and end-of-arm tools.
CL5: Production Planning and Control	- Design and ~~optimization~~optimisation of production planning and adjust work schedules to maintain efficient shift operation. - Plan maintenance processes to ensure satisfactory performance and compliance with specifications and regulations. - Use of statistical methods and tools for process monitoring and product measurements. - Apply integrated HSE systems (International Organization for Standardization (ISO) 9001, 14001, 45001 and other standards). - Improve production rates, efficiencies, yields, costs, and changeovers of products and processes. - Plan, monitor and report on the budget.
CL6: Logistics and Supply Chain Management	- Apply mathematical models for anticipating demand, solving/~~optimization~~optimisation problems in aggregate planning, inventory management and resource exploitation. - Monitor and control the flow of supplies that includes the purchase, storage, and movement of the required quality of raw materials and work-in-progress inventory. - Manage supply chain activities and ~~synchronize~~synchronise supply with demand of ~~production~~products and customers.

4.2 ~~-~~Evaluation of the *Industrial* engineer archetype ~~sustainability evaluation~~contribution to Sustainable Development (SD)

~~Five independent sets of scores have been provided by five different teams. Each team has blindly assigned a correlation score on how each of the identified six competence clusters (CL1-CL6) is aligned to I4.0~~

subenablers (E1.1-E9.2). Table 4 in appendix shows the inferenced scores. The right side of Table 4 recalls the correlation between I4.0 and SDGs from [13]. The values have been normalized to the maximum value of 3 (light blue header) to provide a 0-100 range. For each column CL1-CL6, the weighted mean of the scores on each SDGs column (SDG1-SDG17) has been calculated using the Algorithm 1. A Visual representation that highlights a typical "signature" of the *industrial* engineer is provided as radar plots shown and discussed in section 4.3.

4.3 Results

An evidence emerged from the *industrial* engineer case study. The graphical representation for the six clusters (CL1 to CL6) is shown in Figure 5: the radar plots display the weighted mean values obtained by the computation Algorithm 1, normalized in the 0-100 range for the 17 SDGs. Each cluster of competences CLx presents the same shape, which can be clearly observed for all the six clusters of competences of an *industrial* engineer. This proves that and *industrial* engineer archetype shows the same I4.0 signature on sustainability that was observed in [13]. Only some of the SDGs are aligned to the competences of an *industrial* engineer. Despite the different technological imprinting that characterizes the identified clusters of competences, a one-to-one comparison between each cluster highlights an evident recurrent and confined pattern.

Output from the team scoring activity is presented in section 3.2 at step I, where five different teams have provided five independent sets of scores within the project consortium. Each team has blindly assigned a correlation score on how each identified six competence clusters (CL1-CL6) is aligned to I4.0 technology elements (E1.1-E9.2). Table 5 in Appendix 1 shows the average scores for the final matrix **B**.

By following the methodology presented in section 3.2 at step II, and using the matrix **A** in Table 4 (Appendix 1), the final matrix **C**=**BA** with weighted elements is computed. The final result is reported in Table 6, Appendix 1.

A visual representation of the results in the form of radar plots that highlights a typical "signature" of the *industrial* engineer is obtained using the final scores of matrix **C** (see Figure 4).

The following observation emerged from the *industrial* engineer case study. The graphical representation for the six clusters (CL1 to CL6), i.e., the radar plots, display the weighted mean values obtained by the computation Algorithm 1, normalised in the 0-100 range for the 17 SDGs. Each cluster of competences CLx presents the same shape, which can be observed for all the six clusters of competences of an *industrial* engineer. However, only some of the SDGs are aligned to the competences of an *industrial* engineer. Despite the different technological imprinting that characterises the identified clusters of competences, a one-to-one comparison between each cluster highlights an evident recurrent and confined pattern. For a broader discussion, see Appendix 2.

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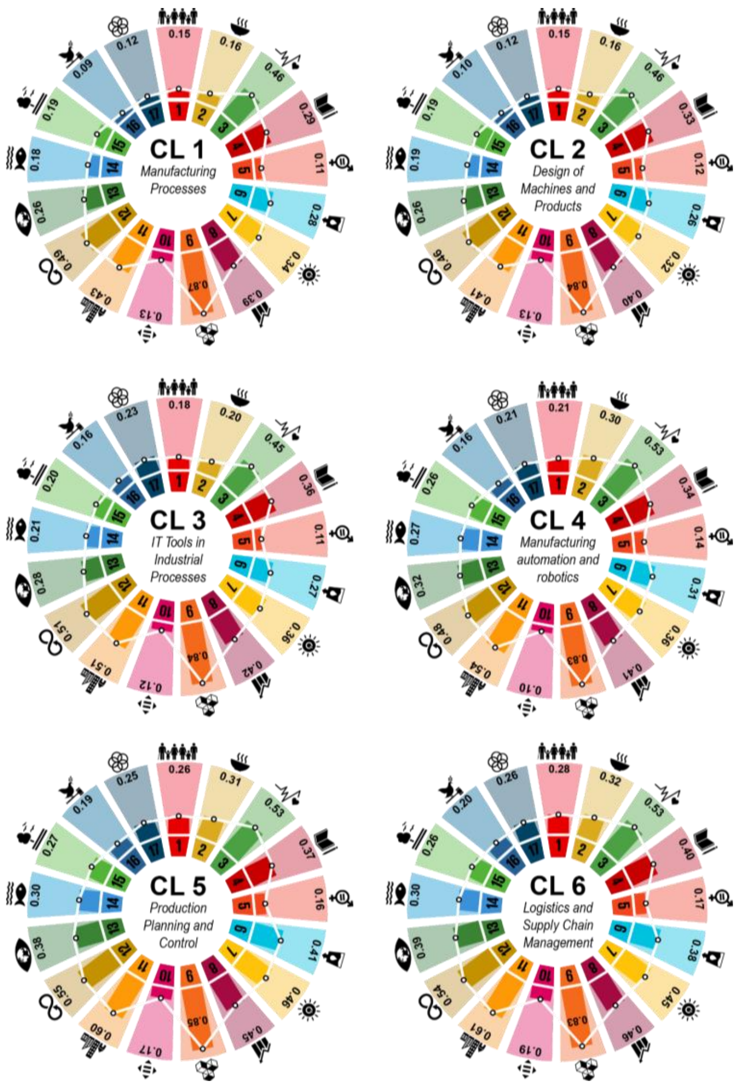

Figure ~~5~~4: Sustainability mapping on the 17 SDGs of the proposed *industrial* engineer archetype.

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4.3 Interpretation of *Industrial* engineer archetype contribution to Sustainable Development (SD)

For a deeper understanding of the results in Figure ~~5~~4, the score distribution is further investigated. Figure ~~6~~5 shows the variability of the weighted average of each SDG score, given by the teams of experts, output from the inferencing algorithm. The boxplots are based on the values of the radar diagrams ~~of~~in Figure ~~5~~4, considering each team separately. At a glance, SDG9 is the goal that presents the lowest variability and the highest weighted mean. After all, the intrinsic relation with I4.0 and *SDG9: Industry, Innovation, and Infrastructure* is ~~quite~~ intuitive and ~~is~~ demonstrated by the unanimous scores. Conversely, *SDG 11: Make cities* *and human settlements inclusive, safe, resilient, and eco-friendly* presents the highest variability showing the different perspectives ~~related to~~of this goal. *SDG5: Gender Equality* and *SDG10: Reduced Inequality* present the lowest weighted means with ~~a~~ low variability, thus demonstrating the limited impact that an *industrial* engineer can have on those aspects.

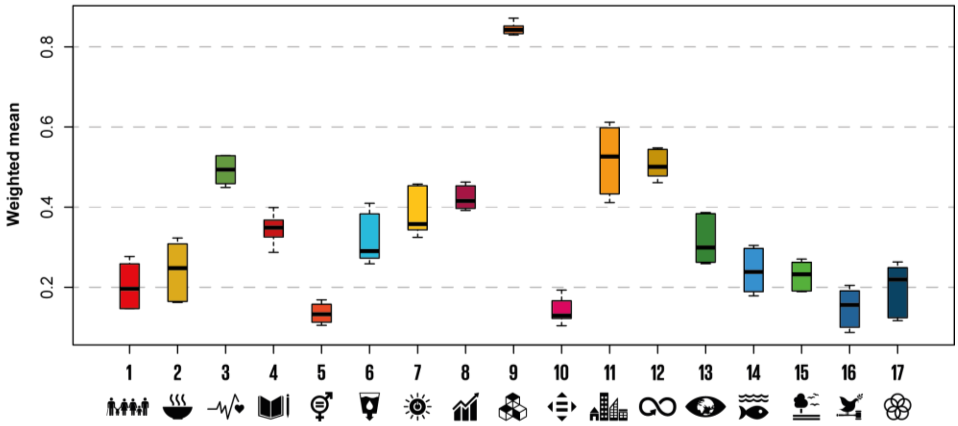

Figure ~~6~~5: Boxplots of the distribution of the weighted mean of each SDG score, given by the teams of experts, output from the inferencing algorithm.

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Summarizing, the identified signatures of Figure 4 could be justified by the argument that I4.0 technology elements will have an unequal influence on the goals. For example, an *industrial* engineer would contribute to SDG9 to a greater extent than other SDGs since it works in the industry. As shown in Figures 4 and 5, the effect of I4.0 is mainly covering SDG3, SDG9, SDG11 and SDG12 in all the six CLx. Taking CL6 and CL1 as an example of the highest absolute difference (still relatively low) observed in the pairwise comparison among clusters of competences, additional observations follow. CL6 presents a better overall impact on all the 17 goals except SDG9 because logistic and supply chain is a set of topics embedded in the management scenario that significantly affects the SD aspects. On the other hand, CL1 is relatively confined to heavy technical disciplines related to manufacturing processes.

The above mentioned considerations mainly apply to the other engineer archetypes, which include technical and managerial skills, which are nevertheless required by an integrated view according to the 17 UN-SDGs. However, the next generation of engineer archetypes should consist of more social and environmental aspects to encompass a holistic approach to contribute to SD [34] significantly. Tejedor et al. [70] stated that an engineer contributing to SD requires creating new long-term, participatory, solution-oriented programs. This approach, which is pretty far from being reached, would provide platforms to recognise and engage with the macro-ethical, adaptive, and cross-disciplinary challenges [71].

Despite the answers to the paper's two research questions, this work opens even more research questions: Does a more standard description for *industrial* engineers exist in contrast to the one depicted in this paper? What are the constraints to "extend" the identified *industrial* engineer sustainability signature? What can remove the "inertia effect" that frequently freezes the improvement dynamics due to lack of communication between different disciplines, bureaucracy, and competition or external barriers? [5].

We still believe that many studies, implementation cases, and dissemination events are needed toward sustainable curricula in *industrial* engineering, which is the starting point.

5 Discussion

The development of frameworks such as the one presented in this work stimulates the standardisation of engineers. Furthermore, it contributes to encouraging SD contribution evaluation by using the I4.0 revolution as the core concept.

Briefly focusing on the possible uses of the results provided for the *industrial* engineer case study we recall:

- Use the generated *industrial* engineer archetype (see Table 3) as a baseline for those stakeholders involved in courses design, communication, comparison and evaluation. It could provide new ideas and align education programs from diverse institutions or training courses from different companies.
- Use the analysis conducted to evaluate the *industrial* engineer archetype contribution on SD for the redefinition of the SS-ILOs. For example, new courses could embrace specific I4.0 technology elements filling the gap on particular SDGs. However, to insert new courses in the current archetypes, a fundamental constraint must be evaluated: a specific course must increase the SD of the overall program. This constraint can be assessed using the "as is" mapping provided in Figure 4, in contrast to the "to be" or future mapping. In this framework, the MAESTRO partners are currently investigating methods to improve old and new *industrial* engineer educational SS-ILOs on SD.

The proposal of a methodology for a *standard* engineer archetype definition as the answer to the **RQ1** is the milestone for numerous stakeholders that seek to evaluate, design, compare or communicate a specific type of engineer. Furthermore, as demonstrated in this work, the preparatory step of archetype definition opens numerous applications, such as answering the **RQ2** by developing a method for "as is" (or "to be") mapping and evaluation of how much the archetype contributes to SD.

Beyond the latter, numerous frontiers can be explored, and uncountable applications can be implemented. For example, as a natural consequence of the SD contribution evaluation, it is possible to measure the progress in the transition toward SD. These measures provide a ground to define educational courses for academic and occupational learning and harmonise it with the SDGs. Notably, when, such as nowadays, the set of competences will extend rapidly, we will need to be prepared for this change.

Our aim is thus to develop a framework that could provide tools, methodologies, and hints to promote a structured approach in contributing to the archetype definition and SD by using I4.0 as a core concept for engineering disciplines. Furthermore, since we focused on the European scenario, competences replacement/integration should be considered by those stakeholders who would apply our methodology locally/globally. For example, the United States Occupational Information Network (O*NET) [72] could be adopted as opposed to/together with the ESCO database. Similarly, United States university courses can be used for the SS-ILOs extraction.

As for future development, we aim to address the following points.

- ***Improve the archetype definition methodology:*** The proposed methodology for defining archetypes can be improved by a more systematic and automated input of competences: SS-ILOs and occupational skills. Text mining [73] method for automatic archetype definition is currently under development and promising partial results have been raised.
- ***Multidisciplinary collaboration for defining the archetypes:*** The proposed method's reliability and validity can be improved by the partnership of experts from academia, research, industry globally or locally. With a particular focus on integrating the industry perspective in the working team, we suggest at least one figure from the industry. Increasing the feedback and connection from modern I4.0 factories to academic experts would align educational and occupational I4.0 competencies in a transdisciplinary way [74].

- ***Alternative archetypes and SD contribution assessment:*** Possible application for the archetype definition can be extended to non-engineering figures, e.g., economics, mathematics, life, art and social sciences, by following the same approach based on SS-ILOs and occupational skills. However, extending the mapping of the SDGs to a general archetype without passing through the I4.0 technologies requires investigation, particularly involving non-technical profiles in which a weaker connection to I4.0 exists. For this reason, we would integrate soft skills (e.g., good communication, teamwork) with hard skills (I4.0 technical aspects) that characterise our method. This integration could allow the adoption of such mapping method even to non-I4.0 related archetypes and increase the related (i.e., engineering) validity [75].

Procedural approaches are needed to harmonise existing content with SD and add new contents that could speed the transition toward sustainability. This article's methods initiate and promote the culture of defining and measuring the progress and evolution toward the SD path. We hope that additional actual use cases, worldwide contributions and investigation on this tremendously important topic would enhance the proposed framework.

6 Conclusion

This paper has investigated the extent to which an industrial or I4.0 engineer can realise the 2030 Sustainable Agenda of the United Nations strategic objectives. We started by defining a standardised professional archetype, integrating academic and occupational skills. Then, a method to quantify its SD contribution has been proposed: indirectly through a mapping of I4.0 on the SDGs. This method initiates and promotes defining and measuring the progress and transition toward the SD path.

The proposed method has been applied to define an *industrial* engineer archetype; its main competences CLx are clustered in six areas. The 44 I4.0 technology elements have been mapped on these clusters and the UN-SDGs. The SDGs standardised view provides a holistic approach, integrating SD and I4.0 contents. Observing the intersection between SD and *industrial* engineer archetypes, it is no surprise that a high degree of sustainability is present. Both I4.0 enablers and SD principles have been present in engineering archetypes for a long time. However, a confined impact on particular SDGs has been observed. Thus, while there may be an evolution of the current *industrial* engineer archetype SD, there is no certainty that it will significantly impact the trilobate-shaped SDG signature shown in the radar plots. As far as sustainability can be pushed, engineers will always have a deep but specific focus on their educational paths and professional careers. These characteristics show the need for an integrated approach to SD by experts from different fields with matching signatures.

As a final conclusion, we argue that (industrial) engineers and no single discipline on its own scarcely present a solution for achieving all the SDGs. This fact is mainly due to the intrinsic integrated and indivisible balancing on the three economic, social, and environmental dimensions of SD. These dimensions need support from professionals with different backgrounds to achieve an actual integrated coverage of SDGs through interdisciplinary approaches, which can be objectively identified by the method proposed in this paper.

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Appendix 1: *Industrial* engineer A, B and C matrices

A		Sustainable Development Goals																
		SDG1	SDG2	SDG3	SDG4	SDG5	SDG6	SDG7	SDG8	SDG9	SDG10	SDG11	SDG12	SDG13	SDG14	SDG15	SDG16	SDG17
Industry 4.0 E1	E1.1	0.24	0.29	0.57	0.24	0.10	0.29	0.33	0.38	0.90	0.19	0.52	0.48	0.33	0.29	0.33	0.10	0.24
	E1.2	0.24	0.38	0.62	0.10	0.10	0.38	0.33	0.29	0.81	0.10	0.71	0.57	0.33	0.33	0.43	0.10	0.14
	E1.3	0.24	0.38	0.57	0.43	0.05	0.33	0.43	0.43	0.90	0.05	0.81	0.62	0.14	0.10	0.19	0.10	0.19
	E1.4	0.19	0.14	0.67	0.48	0.05	0.48	0.48	0.33	0.90	0.00	0.57	0.52	0.38	0.38	0.38	0.24	0.19
	E1.5	0.33	0.33	0.67	0.43	0.14	0.38	0.48	0.48	0.90	0.19	0.81	0.57	0.33	0.29	0.29	0.33	0.33
	E1.6	0.14	0.14	0.43	0.24	0.05	0.29	0.33	0.29	0.71	0.05	0.67	0.38	0.24	0.14	0.19	0.14	0.24
E2	E2.1	0.24	0.33	0.76	0.10	0.14	0.62	0.48	0.38	0.81	0.10	0.71	0.57	0.62	0.52	0.52	0.19	0.10
	E2.2	0.43	0.52	0.67	0.52	0.24	0.62	0.62	0.52	0.71	0.29	0.81	0.48	0.71	0.52	0.38	0.33	0.29
	E2.3	0.38	0.48	0.67	0.48	0.33	0.62	0.62	0.48	0.71	0.33	0.81	0.57	0.67	0.57	0.43	0.43	0.48
	E2.4	0.38	0.48	0.57	0.48	0.24	0.48	0.38	0.33	0.62	0.19	0.52	0.52	0.48	0.38	0.33	0.33	0.33
	E2.5	0.33	0.24	0.67	0.62	0.29	0.62	0.43	0.52	0.81	0.24	0.62	0.52	0.57	0.48	0.33	0.33	0.33
	E2.6	0.38	0.57	0.67	0.52	0.33	0.71	0.62	0.19	0.81	0.19	0.81	0.57	0.62	0.52	0.38	0.33	0.38
	E2.7	0.71	0.81	0.76	0.62	0.33	0.81	0.71	0.52	0.90	0.38	1.00	0.57	0.71	0.62	0.48	0.43	0.48
	E2.8	0.38	0.48	0.57	0.43	0.29	0.62	0.62	0.52	0.81	0.48	0.71	0.48	0.52	0.38	0.38	0.33	0.33
E3	E3.1	0.33	0.29	0.33	0.38	0.05	0.14	0.29	0.05	0.90	0.10	0.67	0.52	0.14	0.10	0.10	0.19	0.38
	E3.2	0.14	0.24	0.29	0.19	0.05	0.24	0.38	0.33	0.90	0.00	0.76	0.43	0.14	0.10	0.10	0.33	0.52
	E3.3	0.10	0.10	0.24	0.48	0.05	0.10	0.48	0.52	0.90	0.29	0.62	0.57	0.24	0.05	0.05	0.19	0.38
	E3.4	0.14	0.05	0.05	0.24	0.00	0.05	0.33	0.33	1.00	0.10	0.33	0.43	0.19	0.00	0.00	0.14	0.29
E4	E4.1	0.14	0.05	0.33	0.43	0.05	0.33	0.38	0.62	0.90	0.10	0.43	0.62	0.24	0.19	0.14	0.05	0.05
	E4.2	0.14	0.10	0.43	0.29	0.05	0.14	0.38	0.57	0.81	0.10	0.38	0.71	0.14	0.00	0.05	0.00	0.00
	E4.3	0.05	0.10	0.48	0.29	0.05	0.29	0.43	0.62	0.81	0.05	0.43	0.57	0.19	0.10	0.10	0.00	0.10
E5	E5.1	0.05	0.10	0.48	0.81	0.24	0.05	0.14	0.62	0.90	0.14	0.14	0.24	0.24	0.14	0.14	0.00	0.00
	E5.2	0.14	0.10	0.52	0.81	0.38	0.05	0.10	0.71	0.90	0.19	0.43	0.48	0.29	0.29	0.29	0.14	0.29
	E5.3	0.24	0.10	0.52	0.90	0.33	0.05	0.29	0.71	0.81	0.24	0.43	0.43	0.29	0.19	0.19	0.05	0.19
	E5.4	0.10	0.05	0.52	0.71	0.19	0.10	0.19	0.52	0.81	0.19	0.48	0.57	0.38	0.33	0.33	0.19	0.24
	E5.5	0.05	0.05	0.48	0.71	0.24	0.05	0.19	0.52	0.81	0.14	0.29	0.38	0.29	0.24	0.29	0.05	0.00
E6	E6.1	0.00	0.00	0.38	0.10	0.05	0.24	0.24	0.19	1.00	0.14	0.24	0.43	0.24	0.14	0.19	0.00	0.00
	E6.2	0.00	0.00	0.38	0.05	0.05	0.24	0.24	0.19	1.00	0.14	0.24	0.48	0.24	0.05	0.10	0.00	0.00
	E6.3	0.00	0.00	0.38	0.05	0.05	0.24	0.33	0.19	0.90	0.14	0.29	0.43	0.10	0.00	0.05	0.00	0.00
	E6.4	0.10	0.10	0.48	0.10	0.10	0.29	0.33	0.29	0.90	0.14	0.29	0.43	0.19	0.14	0.19	0.00	0.00
	E6.5	0.00	0.00	0.38	0.10	0.05	0.05	0.14	0.29	0.71	0.05	0.14	0.29	0.05	0.00	0.05	0.00	0.00
	E6.6	0.00	0.00	0.29	0.10	0.05	0.05	0.14	0.29	0.71	0.05	0.10	0.29	0.05	0.00	0.00	0.00	0.00
E7	E7.1	0.05	0.10	0.10	0.05	0.00	0.19	0.24	0.19	0.71	0.05	0.29	0.52	0.05	0.00	0.05	0.00	0.19
	E7.2	0.10	0.10	0.19	0.14	0.00	0.14	0.24	0.38	0.81	0.00	0.14	0.48	0.05	0.05	0.05	0.00	0.05
	E7.3	0.14	0.19	0.48	0.24	0.05	0.19	0.38	0.57	1.00	0.10	0.57	0.62	0.24	0.19	0.24	0.14	0.33
	E7.4	0.14	0.19	0.33	0.29	0.05	0.24	0.43	0.48	1.00	0.05	0.48	0.57	0.14	0.14	0.19	0.14	0.29
	E7.5	0.14	0.14	0.48	0.38	0.10	0.24	0.38	0.52	1.00	0.05	0.48	0.57	0.33	0.19	0.19	0.14	0.38
	E7.6	0.10	0.10	0.38	0.24	0.05	0.19	0.33	0.43	0.81	0.05	0.38	0.52	0.24	0.19	0.19	0.05	0.29
	E7.7	0.48	0.52	0.43	0.38	0.14	0.29	0.52	0.43	0.90	0.24	0.71	0.52	0.24	0.29	0.19	0.33	0.57
E8	E8.1	0.14	0.48	0.52	0.14	0.19	0.14	0.19	0.33	0.81	0.00	0.38	0.33	0.29	0.33	0.29	0.14	0.14
	E8.2	0.14	0.38	0.52	0.24	0.29	0.24	0.29	0.33	0.81	0.00	0.38	0.33	0.29	0.33	0.29	0.14	0.14
	E8.3	0.19	0.43	0.62	0.24	0.10	0.10	0.14	0.33	0.76	-0.1	0.43	0.24	0.24	0.24	0.24	0.05	0.05
E9	E9.1	0.10	0.10	0.43	0.24	0.05	0.24	0.19	0.29	0.62	0.05	0.62	0.38	0.05	0.05	0.05	0.33	0.33
	E9.2	0.10	0.10	0.43	0.19	0.05	0.29	0.24	0.29	0.62	0.05	0.62	0.43	0.19	0.14	0.14	0.33	0.33

Table 4: Matrix **A** = E1.1- E9.2 & SDG1-SDG12 as a result of our previous paper [24]. The values have been normalised to the maximum value of 3 to provide a 0-100 range. Please note how **A** share the same I4.0 technology elements dimension (i.e., E1.1-E9.2) as the matrix **B** shown in Table 5.

B		Industry 4.0 E1						E2							
		E1.1	E1.2	E1.3	E1.4	E1.5	E1.6	E2.1	E2.2	E2.3	E2.4	E2.5	E2.6	E2.7	E2.8
Industrial Engineer Archetype	CL1	1.00	3.00	2.25	2.25	0.75	0.75	1.50	0.75	0.75	0.25	0.25	0.75	4.50	0.75
	CL2	0.75	0.25	0.75	1.00	0.25	0.25	2.75	1.00	0.75	0.75	0.75	2.25	2.25	2.50
	CL3	4.00	1.50	5.25	5.25	1.00	0.75	3.25	3.75	1.50	3.75	3.25	3.00	3.00	3.25
	CL4	7.00	2.25	3.75	3.25	1.75	1.75	3.75	3.25	1.50	1.00	1.00	2.25	4.75	1.00
	CL5	1.75	1.00	0.25	0.75	0.25	0.75	3.00	3.25	5.50	0.75	0.75	6.00	7.00	1.50
	CL6	3.25	1.00	1.00	0.25	1.00	0.25	1.00	4.75	5.00	0.25	0.25	3.00	4.75	2.75

B		E3				E4			E5				
		E3.1	E3.2	E3.3	E3.4	E4.1	E4.2	E4.3	E5.1	E5.2	E5.3	E5.4	E5.5
Industrial Engineer Archetype	CL1	0.75	0.25	0.75	0.75	7.00	6.00	3.50	0.75	0.50	2.50	0.75	2.50
	CL2	2.50	0.75	0.25	0.75	6.00	3.75	1.75	3.00	1.00	0.50	1.00	5.25
	CL3	4.00	5.25	5.00	3.50	6.00	4.50	3.25	1.50	1.75	3.25	5.25	5.25
	CL4	2.25	0.75	0.75	1.00	3.00	3.00	3.00	1.00	0.75	0.75	2.25	2.25
	CL5	0.25	0.25	0.25	0.25	5.50	4.00	4.00	0.25	0.25	1.00	0.25	0.25
	CL6	0.75	0.25	1.50	0.75	2.00	7.00	1.75	0.25	1.00	0.50	1.00	1.00

B		E6						E7						
		E6.1	E6.2	E6.3	E6.4	E6.5	E6.6	E7.1	E7.2	E7.3	E7.4	E7.5	E7.6	E7.7
Industrial Engineer Archetype	CL1	7.00	7.50	5.50	4.00	3.50	3.00	0.25	0.25	0.75	1.00	0.25	0.75	0.75
	CL2	2.75	2.75	2.75	5.00	7.50	4.50	0.25	0.25	0.25	0.50	0.75	0.75	0.75
	CL3	1.75	1.25	1.25	0.25	4.50	3.75	5.50	3.00	7.50	5.50	4.00	4.50	1.50
	CL4	0.25	0.25	0.25	0.25	1.00	1.00	2.50	0.50	1.50	1.00	3.00	1.50	0.50
	CL5	1.00	1.00	1.00	1.00	1.00	0.25	1.00	0.50	5.50	4.75	0.75	1.00	0.75
	CL6	0.25	0.25	0.25	0.25	0.25	0.25	1.00	0.50	1.25	0.25	1.00	1.00	2.25

B		E8			E9	
		E8.1	E8.2	E8.3	E9.1	E9.2
Industrial Engineer Archetype	CL1	1.00	1.00	1.00	0.33	0.25
	CL2	0.75	0.75	0.75	0.25	0.25
	CL3	0.75	0.75	0.75	3.50	3.50
	CL4	6.00	6.00	7.50	1.00	1.00
	CL5	0.25	0.25	0.75	0.25	0.25
	CL6	0.50	0.50	0.33	0.50	0.50

Table 5: Matrix **B** = CL1-CLx & E1.1.-E9.2 results from the approach described in section 4.2. Please note how **B** shares the same I4.0 technology elements dimension (i.e., E1.1-E9.2) as the matrix **A** shown in Table 4,

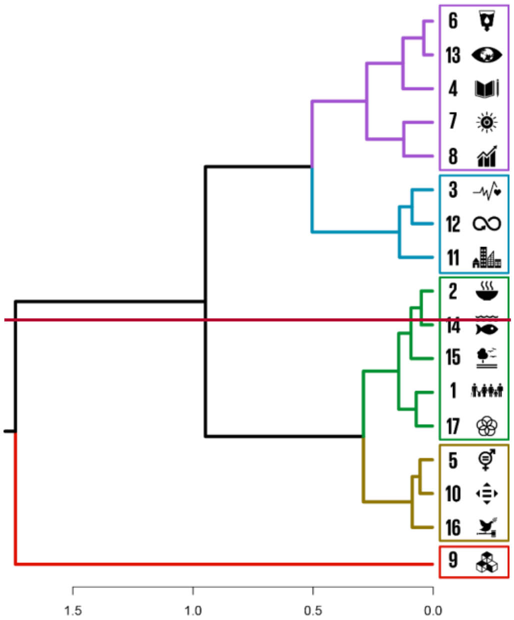
C		Sustainable Development Goals																
		SDG1	SDG2	SDG3	SDG4	SDG5	SDG6	SDG7	SDG8	SDG9	SDG10	SDG11	SDG12	SDG13	SDG14	SDG15	SDG16	SDG17
Industrial Engineer Archetype	CL1	0.15	0.16	0.46	0.29	0.11	0.28	0.34	0.39	0.87	0.13	0.43	0.49	0.26	0.18	0.19	0.09	0.12
	CL2	0.15	0.16	0.46	0.33	0.12	0.26	0.32	0.40	0.84	0.13	0.41	0.46	0.26	0.19	0.19	0.10	0.12
	CL3	0.18	0.20	0.45	0.36	0.11	0.27	0.36	0.42	0.84	0.12	0.51	0.51	0.28	0.21	0.20	0.16	0.23
	CL4	0.21	0.30	0.53	0.34	0.14	0.31	0.36	0.41	0.83	0.10	0.54	0.48	0.32	0.27	0.26	0.16	0.21
	CL5	0.26	0.31	0.53	0.37	0.16	0.41	0.46	0.45	0.85	0.17	0.60	0.55	0.38	0.30	0.27	0.19	0.25
	CL6	0.28	0.32	0.53	0.40	0.17	0.38	0.45	0.46	0.83	0.19	0.61	0.54	0.39	0.30	0.26	0.20	0.26

Table 6: Matrix **C** =**BA**= CL1-CLx & SDG1-SDG12 results from the approach described in section 4.2. Please note how the I4.0 technology elements allowed the algebraic product between **BA**.

Appendix 2: Detailed discussion on the *Industrial* engineer archetype contribution to SD

Based on the values of the weighted average~~,~~ (Table 6, Appendix 1), five groups are identified by hierarchical clustering of the 17 SDGs as shown in the dendrogram in Figure ~~7~~6 and have been ~~characterized~~characterised as follows:

- ***Red SDG-Group:*** *SDG9: Industry, Innovation, and Infrastructure*. As previously highlighted~~ this SDG is highly addressed by~~, the *industrial* engineer archetype highly addresses this SDG since it is the core of I4.0.
- ***Light blue SDG-Group:*** *SDG3: Good Health and Well-being, SDG11: Sustainable Cities and Communities, SDG12: Responsible Consumption and Production*. This group includes technical aspects that combine ~~policy making~~policymaking and cultural habits. As an example, ~~for the SDG12~~ engineers might play a ~~major~~significant role in responsible production~~, but~~. Still, on the other ~~end~~hand, responsible consumption depends on the consumer attitude or regulations imposed by central or local governments~~,~~ outside of the *industrial* engineer field of work.
- ***Purple SDG-Group:*** *SDG4: Quality Education*, *SDG6: Clean Water and Sanitation*, *SDG7: Affordable and Clean Energy*, *SDG8: Decent Work and Economic Growth*, *SDG13: Climate Action*. Similarly~~,~~ to the above Group, these SDGs require a combination of technical actions with policies and culture. For example, engineers may affect the production system efficiency or water treatment plants. Nevertheless, pushing on the achievement of the SDGs of these groups also requires a fundamental contribution from ~~policy makers~~policymakers.
- ***Green SDG-Group:*** *SDG1: No Poverty*, *SDG2: Zero Hunger*, *SDG14: Life Below Water*, *SDG15: Life on Land*, *SDG17: Partnerships to achieve the Goal*. In this group of SDGs, ~~policy making,~~policymaking and ~~economical~~economic factors play a predominant role over technical aspects.
- ***Gold SDG-Group:*** *SDG5: Gender Equality*, *SDG10: Reduced Inequality*, *SDG16: Peace and Justice Strong Institutions.* These SDGs are more related to humanities and social disciplines, and therefore, relatively far from engineering ~~profiles. Additional~~aspects. Therefore, additional and interdisciplinary expertise is needed to ~~deliver~~address the goal within these ~~topics~~SDGs in cooperation with ~~I4.0~~industrial engineers.



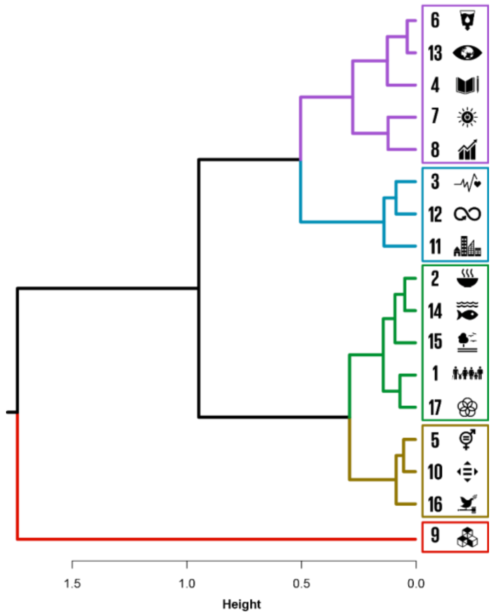


Figure ~~7~~6: Hierarchical clustering of the SDGs

These analyses reinforce our idea that, for ~~a~~ significant coverage of the SDGs, the gap should be filled through the support of experts on the related topics in a contamination framework. A multidisciplinary team is likely to possess a broader range of sustainability abilities, knowledge and skills, and members with different perspectives give a larger pool of resources. Such a diversified team may ~~be helpful in dealing~~help deal with non-routine issues for more creative and innovative problem-solving approaches that could encounter success in a sustainable manner ~~[47]. This concept stays true also if reversed: different professional profiles may require support from (industrial) engineers for an integrated action toward sustainability~~[71]. If reversed, this concept stays true: different professional aspects may require support from (industrial) engineers for an integrated action toward SD.

~~A similar~~Similar hierarchical clustering analysis on the resulting ~~data has been carried out. Three main groups have been identified by hierarchical clustering of the six~~ clusters of competences of the *industrial* engineer has been carried out as shown in the dendogram of Figure ~~8 and~~7. Again, three main groups have been been ~~characterized~~characterised as follows:

- ***Light blue CL-Group****~~: it~~* includes ~~the profiles of~~ IT Tools in Industrial Processes (CL3) and Manufacturing Automation and Robotics (CL4). This group is distinguished by a predominant use of IT tools, digital technologies, and computer~~-~~-related disciplines in I4.0.
- ***Green CL-Group****~~: it~~* includes ~~the profiles of~~ Manufacturing Processes (CL1) and Design of Machines and Products (CL2). This group ~~includes~~contains more traditional engineer ~~profiles~~aspects for ~~the design~~designing and ~~development of~~developing the process and ~~of~~ the product. Although ~~nowadays~~ digital data and ~~Computer Aided Engineering~~computer-aided engineering (CAE) software packages are used in these disciplines, theoretical knowledge and the experimental approach are of paramount importance.
- ***Red CL-Group****~~: it~~* includes ~~the profiles~~aspects of Production Planning and Control (CL5) and Logistics and Supply Chain Management (CL6). These ~~profiles~~aspects are primarily involved in managerial activities and take advantage of the cyber-physical integration of data in I4.0. For decision-making, a comprehensive overview of ~~the~~a product's production state or delivery state ~~of a product~~ with real-time information is required.

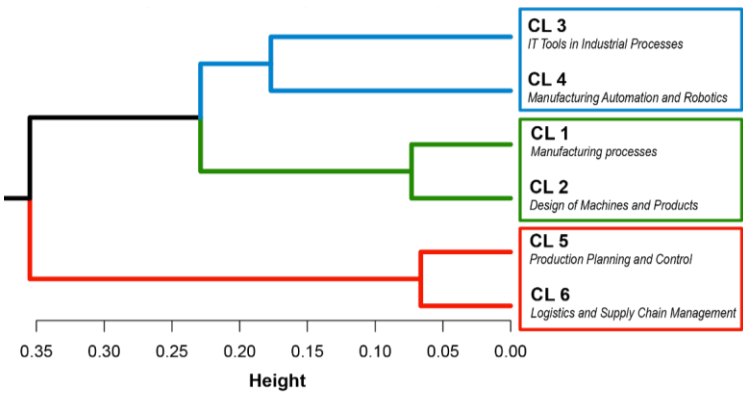


Figure ~~8~~7: Hierarchical clustering of the six clusters of competences of the *industrial* engineer ~~profile~~archetype.

The dendrogram in Figure ~~8~~7 also shows that a further clustering reduces to two groups only: the technical ~~profiles~~aspects from CL1 to CL4 can be grouped separately from the managerial ~~profiles~~aspects CL5 and CL6. ~~From all the previous highlighted analysis on the *industrial* engineer archetype sustainability, MAESTRO partners are currently investigating methods to improve these educational SS-ILOs. We still believe that lots of studies, implementation cases, and dissemination events are needed toward sustainable curricula in engineering.~~

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51 Discussion

As for the interpretation of the *industrial* engineer case study the evidence in Figure 5 could be justified by the argument that I4.0 technologies will have un-equal influence on the goals. As it can be seen the effect of I4.0 is mostly covering SDG3, SDG9, SDG11 and SDG12 in all the six CLx. Taking CL6 and CL1 as an example of the highest absolute difference (still relatively very low) observed in the pairwise comparison among clusters of competences, additional observations follow. CL6 presents a better overall impact on all the 17 goals except SDG9. This could be justified by the fact that logistic and supply chain disciplines are a set of topics embedded in the management scenario that could have broad impact on the sustainability aspects. On the other hand, CL1 is quite confined to heavy technical disciplines related to manufacturing processes, therefore, the highest impact on SDG9 can be reached by focusing less on the other goals.

The following consideration apply to the engineer archetype. A general engineer archetype includes both technical and managerial skills, which are required by an integrated view according to the 17 UN SDGs. However, the next generation engineer archetype should include more social and environmental aspects in order to encompass a holistic approach [23]. The proposed archetype definition methodology is virtually applicable to engineering and non-engineering. A critically may arise in non-engineering programs such as social, mathematical and arts programs, where weaker association exist with industry and technologies.

As for engineering, this methodology allows the harmonization of profiles and their sustainability quantitative monitoring and improvement.

As stated by Tejedor et al. [48], a sustainable engineer requires creating new long-term, participatory, solution-oriented programs as platforms to recognize and engage with the macro-ethical, adaptive, and cross-disciplinary challenges embedded in professional issues that are quite far from being reached. Despite the provided answers to the two research questions of the paper, this work opens more research questions, such as:

- ***Improve the archetype and the definition method:*** The proposed sustainable engineering archetypes can be improved by a more systematic and automated input of competences: SS-ILOs and occupational skills. Procedural approaches are needed to harmonize existing contents with sustainability and to add new contents that could speed the transition toward sustainability.
- ***Multi-disciplinary collaboration for defining the archetypes:*** Defining a collaborative framework of experts from academia, research, and industry for specific curricula from different countries to define archetypes and evaluate sustainability. Does a more sustainable global engineer exist with respect to the one depicted in this paper? What are the constraints to "extend" the identified engineer sustainability signature? What can remove the "inertia effect" that frequently freezes the improvement dynamics due to lack of communication between different disciplines bureaucracy, and competition. Other kinds of issues can be found in external barriers: e.g., lack of incentives [8].
- ***Alternative assessments of the archetype's sustainability:*** Extend mapping of the SDGs to a general archetype without passing through the I4.0 technologies requires investigation, particularly involving profiles from different fields e.g., economics, mathematics, life, and social sciences etc.

61 Conclusion

This paper has investigated the extent for an industrial or I4.0 engineer to realize the 2030 Sustainable Agenda of the United Nations strategic objectives. It has started by defining a standardized professional archetype, integrating academic and occupational skills. A method to quantify its sustainability has been proposed: indirectly through a mapping of I4.0 on the SDGs. This method initiates and promotes the culture of defining and measuring the progress and transition toward the sustainability path.

The proposed method has been applied to define an *industrial* engineer archetype; its main competences CLx are clustered on six areas. The 44 I4.0 subenablers Ex.x have been mapped on these clusters and on the UN SDGs. The SDGs standardized view provides a holistic approach, integrating sustainability and I4.0 contents. Observing the intersection between sustainability and *industrial* engineer archetype it is no surprise that a high degree of sustainability is present. Both I4.0 enablers and sustainability principles have been present in engineering profiles for a long time. However, a confined impact on certain SDGs has been clearly observed. While there may be an evolution of current *industrial* engineer archetype, there is no certainty that it will provide a significant impact on the trilobate-shaped SDG signature.

As far as sustainability can be pushed, engineers will always have a deep but specific focus coming from their educational paths and professional careers. These characteristics show the need for an integrated approach to sustainability by experts from different fields with matching signatures.

As a final conclusion, we, argue that (industrial and I4.0) engineers, but also no single discipline on its own, can present a solution for achieving all the SDGs. This is mainly due to the intrinsic integrated and indivisible balancing on the three economic, social, and environmental dimensions of sustainable development. These dimensions need support from specialists with different backgrounds to achieve a real integrated coverage of SDGs through interdisciplinary approaches, which can be objectively identified by the method proposed in this paper.

Acknowledgement:

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~~Appendix~~

~~**Table 4:** The competences mapping table deduced from MAESTRO team average scoring.~~

Industrial Engineer Archetype						Industry 4.0		Sustainable Development Goals																
CL1	CL2	CL3	CL4	CL5	CL6			SDG1	SDG2	SDG3	SDG4	SDG5	SDG6	SDG7	SDG8	SDG9	SDG10	SDG11	SDG12	SDG13	SDG14	SDG15	SDG16	SDG17
1.00	0.75	4.00	7.00	1.75	3.25	E1	E1.1	0.24	0.29	0.57	0.24	0.10	0.29	0.33	0.38	0.90	0.19	0.52	0.48	0.33	0.29	0.33	0.10	0.24
3.00	0.25	1.50	2.25	1.00	1.00		E1.2	0.24	0.38	0.62	0.10	0.10	0.38	0.33	0.29	0.81	0.10	0.71	0.57	0.33	0.33	0.43	0.10	0.14
2.25	0.75	5.25	3.75	0.25	1.00		E1.3	0.24	0.38	0.57	0.43	0.05	0.33	0.43	0.43	0.90	0.05	0.81	0.62	0.14	0.10	0.19	0.10	0.19
2.25	1.00	5.25	3.25	0.75	0.25		E1.4	0.19	0.14	0.67	0.48	0.05	0.48	0.48	0.33	0.90	0.00	0.57	0.52	0.38	0.38	0.38	0.24	0.19
0.75	0.25	1.00	1.75	0.25	1.00		E1.5	0.33	0.33	0.67	0.43	0.14	0.38	0.48	0.48	0.90	0.19	0.81	0.57	0.33	0.29	0.29	0.33	0.33
0.75	0.25	0.75	1.75	0.75	0.25		E1.6	0.14	0.14	0.43	0.24	0.05	0.29	0.33	0.29	0.71	0.05	0.67	0.38	0.24	0.14	0.19	0.14	0.24
1.50	2.75	3.25	3.75	3.00	1.00	E2	E2.1	0.24	0.33	0.76	0.10	0.14	0.62	0.48	0.38	0.81	0.10	0.71	0.57	0.62	0.52	0.52	0.19	0.10
0.75	1.00	3.75	3.25	3.25	4.75		E2.2	0.43	0.52	0.67	0.52	0.24	0.62	0.62	0.52	0.71	0.29	0.81	0.48	0.71	0.52	0.38	0.33	0.29
0.75	0.75	1.50	1.50	5.50	5.00		E2.3	0.38	0.48	0.67	0.48	0.33	0.62	0.62	0.48	0.71	0.33	0.81	0.57	0.67	0.57	0.43	0.43	0.48
0.25	0.75	3.75	1.00	0.75	0.25		E2.4	0.38	0.48	0.57	0.48	0.24	0.48	0.38	0.33	0.62	0.19	0.52	0.52	0.48	0.38	0.33	0.33	0.33
0.25	0.75	3.25	1.00	0.75	0.25		E2.5	0.33	0.24	0.67	0.62	0.29	0.62	0.43	0.52	0.81	0.24	0.62	0.52	0.57	0.48	0.33	0.33	0.33
0.75	2.25	3.00	2.25	6.00	3.00		E2.6	0.38	0.57	0.67	0.52	0.33	0.71	0.62	0.19	0.81	0.19	0.81	0.57	0.62	0.52	0.38	0.33	0.38
4.50	2.25	3.00	4.75	7.00	4.75		E2.7	0.71	0.81	0.76	0.62	0.33	0.81	0.71	0.52	0.90	0.38	1.00	0.57	0.71	0.62	0.48	0.43	0.48
0.75	2.50	3.25	1.00	1.50	2.75		E2.8	0.38	0.48	0.57	0.43	0.29	0.62	0.62	0.52	0.81	0.48	0.71	0.48	0.52	0.38	0.38	0.33	0.33
0.75	2.50	4.00	2.25	0.25	0.75	E3	E3.1	0.33	0.29	0.33	0.38	0.05	0.14	0.29	0.05	0.90	0.10	0.67	0.52	0.14	0.10	0.10	0.19	0.38
0.25	0.75	5.25	0.75	0.25	0.25		E3.2	0.14	0.24	0.29	0.19	0.05	0.24	0.38	0.33	0.90	0.00	0.76	0.43	0.14	0.10	0.10	0.33	0.52
0.75	0.25	5.00	0.75	0.25	1.50		E3.3	0.10	0.10	0.24	0.48	0.05	0.10	0.48	0.52	0.90	0.29	0.62	0.57	0.24	0.05	0.05	0.19	0.38
0.75	0.75	3.50	1.00	0.25	0.75		E3.4	0.14	0.05	0.05	0.24	0.00	0.05	0.33	0.33	1.00	0.10	0.33	0.43	0.19	0.00	0.00	0.14	0.29
7.00	6.00	6.00	3.00	5.50	2.00	E4	E4.1	0.14	0.05	0.33	0.43	0.05	0.33	0.38	0.62	0.90	0.10	0.43	0.62	0.24	0.19	0.14	0.05	0.05
6.00	3.75	4.50	3.00	4.00	7.00		E4.2	0.14	0.10	0.43	0.29	0.05	0.14	0.38	0.57	0.81	0.10	0.38	0.71	0.14	0.00	0.05	0.00	0.00
3.50	1.75	3.25	3.00	4.00	1.75		E4.3	0.05	0.10	0.48	0.29	0.05	0.29	0.43	0.62	0.81	0.05	0.43	0.57	0.19	0.10	0.10	0.00	0.10
0.75	3.00	1.50	1.00	0.25	0.25	E5	E5.1	0.05	0.10	0.48	0.81	0.24	0.05	0.14	0.62	0.90	0.14	0.14	0.24	0.24	0.14	0.14	0.00	0.00
0.50	1.00	1.75	0.75	0.25	1.00		E5.2	0.14	0.10	0.52	0.81	0.38	0.05	0.10	0.71	0.90	0.19	0.43	0.48	0.29	0.29	0.29	0.14	0.29
2.50	0.50	3.25	0.75	1.00	0.50		E5.3	0.24	0.10	0.52	0.90	0.33	0.05	0.29	0.71	0.81	0.24	0.43	0.43	0.29	0.19	0.19	0.05	0.19
0.75	1.00	5.25	2.25	0.25	1.00		E5.4	0.10	0.05	0.52	0.71	0.19	0.10	0.19	0.52	0.81	0.19	0.48	0.57	0.38	0.33	0.33	0.19	0.24
2.50	5.25	5.25	2.25	0.25	1.00		E5.5	0.05	0.05	0.48	0.71	0.24	0.05	0.19	0.52	0.81	0.14	0.29	0.38	0.29	0.24	0.29	0.05	0.00
7.00	2.75	1.75	0.25	1.00	0.25	E6	E6.1	0.00	0.00	0.38	0.10	0.05	0.24	0.24	0.19	1.00	0.14	0.24	0.43	0.24	0.14	0.19	0.00	0.00
7.50	2.75	1.25	0.25	1.00	0.25		E6.2	0.00	0.00	0.38	0.05	0.05	0.24	0.24	0.19	1.00	0.14	0.24	0.48	0.24	0.05	0.10	0.00	0.00
5.50	2.75	1.25	0.25	1.00	0.25		E6.3	0.00	0.00	0.38	0.05	0.05	0.24	0.33	0.19	0.90	0.14	0.29	0.43	0.10	0.00	0.05	0.00	0.00
4.00	5.00	0.25	0.25	1.00	0.25		E6.4	0.10	0.10	0.48	0.10	0.10	0.29	0.33	0.29	0.90	0.14	0.29	0.43	0.19	0.14	0.19	0.00	0.00
3.50	7.50	4.50	1.00	1.00	0.25		E6.5	0.00	0.00	0.38	0.10	0.05	0.05	0.14	0.29	0.71	0.05	0.14	0.29	0.05	0.00	0.05	0.00	0.00
3.00	4.50	3.75	1.00	0.25	0.25		E6.6	0.00	0.00	0.29	0.10	0.05	0.05	0.14	0.29	0.71	0.05	0.10	0.29	0.05	0.00	0.00	0.00	0.00
0.25	0.25	5.50	2.50	1.00	1.00	E7	E7.1	0.05	0.10	0.10	0.05	0.00	0.19	0.24	0.19	0.71	0.05	0.29	0.52	0.05	0.00	0.05	0.00	0.19
0.25	0.25	3.00	0.50	0.50	0.50		E7.2	0.10	0.10	0.19	0.14	0.00	0.14	0.24	0.38	0.81	0.00	0.14	0.48	0.05	0.05	0.05	0.00	0.05
0.75	0.25	7.50	1.50	5.50	1.25		E7.3	0.14	0.19	0.48	0.24	0.05	0.19	0.38	0.57	1.00	0.10	0.57	0.62	0.24	0.19	0.24	0.14	0.33
1.00	0.50	5.50	1.00	4.75	0.25		E7.4	0.14	0.19	0.33	0.29	0.05	0.24	0.43	0.48	1.00	0.05	0.48	0.57	0.14	0.14	0.19	0.14	0.29
0.25	0.75	4.00	3.00	0.75	1.00		E7.5	0.14	0.14	0.48	0.38	0.10	0.24	0.38	0.52	1.00	0.05	0.48	0.57	0.33	0.19	0.19	0.14	0.38
0.75	0.75	4.50	1.50	1.00	1.00		E7.6	0.10	0.10	0.38	0.24	0.05	0.19	0.33	0.43	0.81	0.05	0.38	0.52	0.24	0.19	0.19	0.05	0.29
0.75	0.75	1.50	0.50	0.75	2.25		E7.7	0.48	0.52	0.43	0.38	0.14	0.29	0.52	0.43	0.90	0.24	0.71	0.52	0.24	0.29	0.19	0.33	0.57
1.00	0.75	0.75	6.00	0.25	0.50	E8	E8.1	0.14	0.48	0.52	0.14	0.19	0.14	0.19	0.33	0.81	0.00	0.38	0.33	0.29	0.33	0.29	0.14	0.14
1.00	0.75	0.75	6.00	0.25	0.50		E8.2	0.14	0.38	0.52	0.24	0.29	0.24	0.29	0.33	0.81	0.00	0.38	0.33	0.29	0.33	0.29	0.14	0.14
1.00	0.75	0.75	7.50	0.75	0.33		E8.3	0.19	0.43	0.62	0.24	0.10	0.10	0.14	0.33	0.76	-0.1	0.43	0.24	0.24	0.24	0.24	0.05	0.05
0.33	0.25	3.50	1.00	0.25	0.50	E9	E9.1	0.10	0.10	0.43	0.24	0.05	0.24	0.19	0.29	0.62	0.05	0.62	0.38	0.05	0.05	0.05	0.33	0.33
0.25	0.25	3.50	1.00	0.25	0.50		E9.2	0.10	0.10	0.43	0.19	0.05	0.29	0.24	0.29	0.62	0.05	0.62	0.43	0.19	0.14	0.14	0.33	0.33

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