Investigation of the Diversity of Engineering Disciplines

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Abstract—**The word engineering is used in various contexts and for a broad range of disciplines. But there is no common understanding for engineering disciplines. It is not clear which disciplines exist, the scope of disciplines is not defined, and there is no common naming conventions for engineering disciplines. This paper shall promote the common understanding of engineering by an investigation on the diversity of engineering disciplines. It is analyzed which engineering disciplines appear in publications and which disciplines are referenced by professional engineering associations and companies or by universities and educational associations. This work shows that the range of engineering disciplines is evolving. Based on our research we created a list of more than 200 engineering disciplines and examined the used names for the different disciplines. A final frequency analysis examines the frequency of occurrence of certain terms. Based on this analysis the disciplines were ranked. It is shown that disciplines are evolving, that there are some major disciplines, and that newer disciplines are on the advance.**

I. INTRODUCTION

The Encyclopedia Britannica defines Engineering as "the application of scientific principles to the optimal conversion of natural resources into structures, machines, products, systems, and processes for the benefit of humankind." [1] Most engineers would agree that engineering usually refers to a certain discipline, usually a technical one [2][3]. Of these disciplines in turn, there is a wide bandwidth, starting with well-known disciplines such as Electrical or Mechanical Engineering. Other disciplines such as Astronautical Engineering or Optical Engineering are less well known. Industrial companies offer several types of services in different engineering disciplines. In part, they offer services in disciplines which are not common. For example the OGIS GmbH [4] and Thomasons [5] refer to the discipline Glass Engineering, which is also the name of a forum in the popular engineering community Eng-Tips [6]. In addition to these technical disciplines companies offer services in disciplines without a technical relationship, for example Social Engineering [7], Authority Engineering [8] or Financial Engineering [9].

Certain sources limit the number of disciplines to a small amount. In the renowned Encyclopedia Britannica of 1990, engineering disciplines are divided into the four primary branches Civil, Mechanical, Electrical, and Chemical Engineering. The four primary branches are subdivided into seventeen sub-categories [1]. This is a total of 21 disciplines. The Oxford Thesaurus of 1996 lists a total of 20 different disciplines without further structure [10]. The Accreditation Board for Engineering and Technology (ABET)[1] defines 28 engineering programs (comparable engineering disciplines) for accreditation [11]. The Institution of Engineers Australia (2013) speaks of four broad disciplines, which are divided in so-called major fields, 18 of these major field are listed on their website. A detailed view into the description presents more than 40 mentioned disciplines [12]. But there are sources which speak of much higher numbers of engineering disciplines. The Queen's University claims that there are more than 200 types of engineering, a total of 38 types are listed on the homepage of the university [13]. A search for engineering programs in the German "Hochschulkompass"[2] database has about 500 results, with more than 100 different types of engineering programs [14].

These few examples show that there is a wide field of engineering disciplines and that there are different points of view on them. It also shows that there is no defined number of engineering disciplines. Along with that there is no clear and no common definition of engineering disciplines. There are no rules about the scope of certain engineering disciplines and in fact everybody can define disciplines on his own. What is an engineering discipline lies in the eye of the beholder and depends on his perspective.

A better understanding of engineering disciplines and a common understanding of the scope of engineering disciplines can provide more transparency in this area. This research seeks to analyze diversity of engineering disciplines to make a step in direction of a common understanding of engineering disciplines with the target of more transparency of engineering disciplines and their scope.

II. METHODOLOGY

This research is based on three different views on engineering and therefore focuses on three sources of information, which are explained below. One component of this research is a qualitative research about the use of terms and the occurrence of engineering disciplines in these sources of information. Additionally, a frequency analysis about the frequency of occurrence of the identified disciplines is conducted. Both approaches are explained in more detail below.

[1] ABET accredits educational programs.
[2] The database provides an overview of educational programs at universities in Germany. Target group are students who are looking for degree programs. Universities can enter their programs in the list. There are no naming rules. As result there are different names for the same discipline.

A. Qualitative study - different views on engineering

In the first part of the study the use of the term "engineering discipline" is analyzed. In this context the spectrum of disciplines is investigated. It is compared which terms are used in context with engineering disciplines and a list of all disciplines mentioned anywhere is created. For a comprehensive picture, we have considered the following three views on the subject (Fig. 1):

- **Linguistic view on engineering** – The meaning of engineering disciplines in the language is examined using the information in dictionaries, thesauri and encyclopedias. This view provides a basic picture of the diversity of engineering disciplines.
- **Academic view on engineering** – For this view we analyzed the educational programs of technical universities and publications of engineering related organizations. This includes scientific publications and databases. Based on this information, we have a current picture of the disciplines that are represented in science.
- **Industrial view on engineering** – This view is based on information and publications of engineering companies, internet platforms and industrial associations in the field of engineering it hence represent the industry view.

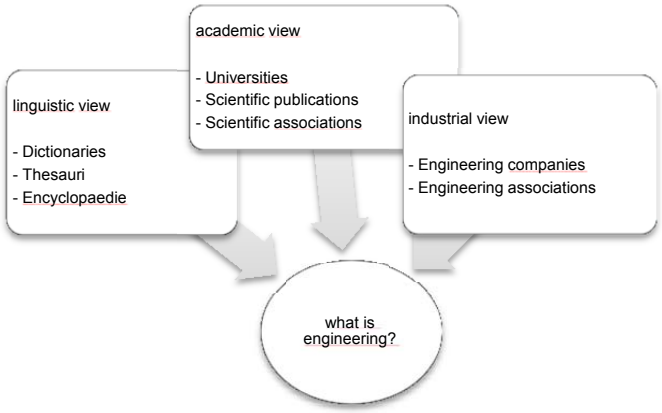

Figure 1: Different views on engineering.

For each view we merged the listed disciplines of various sources to an extensive list of disciplines. The different typologies and naming schemes were analyzed and the temporal occurrence was investigated. Because several sources list just a small amount of disciplines, not all sources are referenced in this paper. But the internet provides several "lists" of engineering disciplines which were considered and referenced. The source of a disciplines name is not relevant, because the scope of disciplines or the creation of a hierarchical order is not part of this study. This shall be the subject of future research.

B. Frequency Analysis

As approach to investigate the significance of the disciplines we used a frequency analysis. The resulting list of engineering disciplines was queried in popular Internet search engines. The total number of hits is used as an indicator of the relevance of the individual disciplines. For an acceptable result, the search was performed in the three most popular search engines Bing, Google, and Yahoo [15][16]. The search terms have been formed according to the nomenclature "<engineering field> + Engineering" (see results for details).

There are some major challenges in this type of research. One is the context of the term. As the results go up to more than 21 million hits per term, it is not possible to analyze their context or analyze a representative number of hits for each of the disciplines. Therefore, only the number of hits was taken into account.

Another challenge is the occurrence of outliers with a difference of more than 100% in the number of hits between two search requests for the same term in one search engine. During the research, such results were removed, as it seemed unusual when the number of hits varies e.g. between 4.010.000 and 21.100.000 within days or even hours. To avoid such errors six queries per search term and engine were executed. Always two queries per day were executed. In case there were outliners as mentioned above within the six numbers of hits, this result was removed and all six requests were repeated[3]. For all six results we calculated the mean number of hits for each discipline per search engine. This results in three hit lists for all disciplines.

As the number of hits varied significantly between the search engines it is difficult to compare the absolute figures. So we set the highest number of hits to 100% for each engine and calculated the relative percentage. Then the three results were combined to a final frequency ranking.

Finally, this frequency ranking was compared to the results of the qualitative approach.

III. RESULTS

A. Naming of discplines

A first finding is that the naming of engineering disciplines is inconsistent within the different information sources. "Disciplines" are referred as branches, types, fields, (sub-) categories, areas or disciplines. In Oxford Thesaurus (1996), a total of twenty disciplines are listed which are not clustered [10]. The Encyclopedia Britannica (1990), on the other hand, divides the engineering disciplines into the four primary branches Civil, Mechanical, Electrical, and Chemical Engineering with a total of seventeen sub-categories [1]. Even if this division into branches and sub-categories is not found in the current online version of Encyclopedia Britannia (2013), these branches are referred as first historical disciplines in engineering [17]. The Institution of Engineers Australia (2013) defines four broad disciplines, subdivided into 18 major fields [12]. The Queen's University (2013) claims that there are more than 200 types of engineering that can be

[3] If one of the samples had a deviation of more than 15% to the average value a new request was done for this sample. In case more than one of the samples deviated from the average value a new series of six values was performed for this term.

divided into seven areas [13]. Associations like the American Association of Engineering Societies (AAES) [18] or the National Society of Professional Engineers (NSPE) [19] speak of disciplines only. The online Encyclopedia Britannica has a mix of the term branch, field, discipline and area, without a clear hierarchical order [17][20][21]. In following the term disciplines is used for engineering disciplines, because this term is used most commonly (see Table 1).

TABLE 1: OVERVIEW OF THE USED TERMS FOR DISCIPLINES

Source	Naming and hierarchical approach
Encyclopedia Britannica (print)	branches → sub-categories
Encyclopedia Britannica (online)	fields, branches, areas → **disciplines**, branches
Oxford Thesaurus (print)	**disciplines**
Wikipedia (online)	branches / **disciplines** → sub-**disciplines** → major specialities
Science Daily (online)	**disciplines** /fields → sub-**disciplines**
Queens University (online)	areas → types
TryEngineering.com (online)	**disciplines** / fields
Engineers Australia (online)	**disciplines** → branches → (major) fields
AAES (online)	**disciplines**
NSPE (online)	**disciplines**

Besides the inconsistency in naming of layers, the disciplines themselves have no consistent naming scheme. The word "engineering" is not always used, e.g. for Astronautics and Ergonomics Engineering [22]. Furthermore, a differentiation of certain disciplines is questionable, for example, "Electronic Engineering" and "Electronics Engineering" or "Agriculture Engineering" and "Agricultural Engineering" (TABLE 2). Additionally, several disciplines seem to be equal from scope, e.g. "Energy Resources Engineering" and "Petroleum Engineering" [23]. There are also examples, where a discipline is combined with a technical field. There is for example "Production Systems Engineering", "Automotive Systems Engineering" or "Electronic Systems Engineering". These disciplines can be seen as sub-types of "Systems Engineering" or as dedicated disciplines.

The focus of this work is diversity and the naming of engineering disciplines. Thus, all disciplines were added to a list, whether they seem to be equal or not. As a unified naming and research scheme the convention "<engineering field> + Engineering" (e.g. Electrical Engineering) is used in the following.

TABLE 2: EXAMPLES FOR SIMILAR NAMES

Familiar Engineering Terms	
Agricultural Engineering	Agriculture Engineering
Communication Engineering	Communications Engineering
Economic Engineering	Economics Engineering
Electronic Engineering	Electronics Engineering
Hydraulic Engineering	Hydraulics Engineering
Material Engineering	Materials Engineering
Mineral Engineering	Minerals Engineering
System Engineering	Systems Engineering

B. Diversity of engineering disciplines

As already mentioned, the statements about the number of disciplines are very different. TABLE 3 shows exemplary sources of lists of engineering disciplines, which were used to create a "complete list" of disciplines which were taken into account. Additionally, scientific publications were searched for the term "engineering" in Science Direct [24] and Google Scholar [25]. The offerings of industrial companies were searched for the term "engineering". Thereby the leading engineering service providers in Germany according to the Lünendonk ranking [26] and worlds ten largest engineering, procurement and construction (EPC) companies according to fortune ranking [27] were considered. Moreover, the educational programs of 15 leading engineering universities [28] were investigated.

All disciplines were combined to a list of more than 200 disciplines. The complete list is published on Research Gate [29]. The frequency analysis was done with all engineering disciplines in this list.

TABLE 3: NUMBER OF DISCIPLINES IN DIFFERENT SOURCES

Type	Source	No. of disciplines
Literature	Encyclopedia Britannica [1]	21
	Oxford Thesaurus [22]	20
Educational	Queens University [13]	38
	University of Berkeley [30]	16
	Hochschulkompass [14]	> 100
	ABET [11]	28
Eng. Organization	Engineers Australia [12]	44
Online portal	Wikipedia [31]	> 100
	Engineers Week [32]	24
	What is Engineering [33]	44
	Try Engineering [34]	16
	Eng-Tips [35]	64
	Dedicated Engineers [36]	14
	Career Cornerstone [37]	18

C. Engineering disciplines in three views

In the following a detailed comparison for renowned sources from the three mentioned views is done. For the linguistic view the Encyclopedia Britannica (print and online) and the Oxford Thesaurus were analyzed. For the academic view the educational programs of the University of Berkeley, the list of engineering types by the Queens University and additionally the programs referenced by two educational associations were investigated. The industrial view is represented by the association of Engineers Australia. This view is limited to one source, because engineering companies are usually specialized in a few disciplines. Thus they don't offer or list a wide field of disciplines and they do not provide overviews about engineering.

TABLE 4 shows an overview of the disciplines that are mentioned by at least half of the sources. The above-mentioned four main branches Chemical, Civil, Electrical and Mechanical Engineering are listed by all sources. This supports the theory that these disciplines have a higher importance compared to other disciplines. Other disciplines are just listed in newer sources, like Biomedical, Industrial, Materials or Petroleum Engineering. 47 disciplines were mentioned in at least one of the newer sources and in none of the older ones. Here, a change in the diversity of disciplines over the time is obvious. The number of disciplines is increasing.

TABLE 4: THREE VIEWS ON THE DISCIPLINES

	Linguistic			Academic			Industrial
Discipline	Britannica	Britannica online	Oxford Thesaurus	Queens University	Hochschul-kompass	ABET	Engineers Australia
Chemical Engineering	x	x	x	x	x	x	x
Electrical Engineering	x	x	x	x	x	x	x
Mechanical Engineering	x	x	x	x	x	x	x
Aerospace Engineering		x	x	x	x	x	x
Civil Engineering	x	x	x	x		x	x
Environmental Engineering		x	x	x	x	x	x
Agricultural Engineering	x	x	x	x		x	x
Electronics Engineering	x	x	x		x	x	x
Industrial Engineering		x		x	x	x	x
Aeronautical Engineering	x	x	x			x	x
Automotive Engineering	x		x	x	x	x	
Production Engineering	x		x	x	x		x
Software Engineering		x		x	x	x	x
Biomedical Engineering				x	x	x	x
Computer Engineering	x			x	x	x	
Materials Engineering				x	x	x	x
Communications Engineering	x			x	x	x	
Metallurgical Engineering				x	x	x	x
Mining Engineering			x	x		x	x
Petroleum Engineering		x		x		x	x

On the other hand there are disciplines like Foundation, Instrument, Irrigation, Municipal, Precision, Traffic and Public Health and Sanitary Engineering which were listed only in Encyclopedia Britannica or Aerodynamics[4] Astronautics, Cosmonautics, Ergonomics and Fluid Dynamics which were listed only in Oxford Thesaurus.

D. Frequency analysis

All disciplines from the resulting list were queried in Bing, Google, and Yahoo. The number of hits was retrieved and ranked. The results from Bing and Yahoo were less scattered than Google and the final ordering war very familiar. In sum had to be repeated at Google 33 values and 7 queries. At Bing these were only 1/1 and in Yahoo 0/3 (TABLE 5).

TABLE 5: CHARACTERISTICS OF RESEARCH

Characteristics	**Bing**	**Google**	**Yahoo**
Maximum number of hits	15.000.000	21.600.000	14.800.000
Minimum number of hits	9	843	26
Average deviation of the respective minimum value from the corresponding mean average	0.19	1.83	0.45
Average deviation of the respective maximum value from the corresponding mean average	0.32	3.09	0.47
Number of disciplines where one value was outliner (repetition of single sample)	1	33	0
Number of disciplines where more than one value were outliners (repetition of series)	1	7	3

The range was from a minimum of nine hits for a discipline (Cosmonautics Engineering in Bing) to a maximum of more than 21 million hits (Electrical Engineering in Google)[5]. Even when the number of results was different for the two engines (the maximum in Bing was 15 million for Electrical Engineering; the maximum in Bing was 14.8 million for Electrical Engineering), the ordering of disciplines was similar. In the top 20 results, 14 (70%) of the disciplines were listed in all three engines. In the top 50, 31 (62%) of the disciplines were listed in all three engines.

For a final picture the rankings of all three engines were merged. We have normalized number of hits to 100% and calculated the average of the three engines for a final ranking. The correlated number of hits for the Internet search is shown in Figure 2 (top 100).

[4] In Oxford Thesaurus these disciplines were used without the word „engineering".

[5] In a former research in September 2013 the highest number of hits was more than 39 million hits for Civil Engineering. Because of an extension of the list of disciplines a new sample was created in April 2014. In this sample the number of hits, especially for Google, was significantly lower.

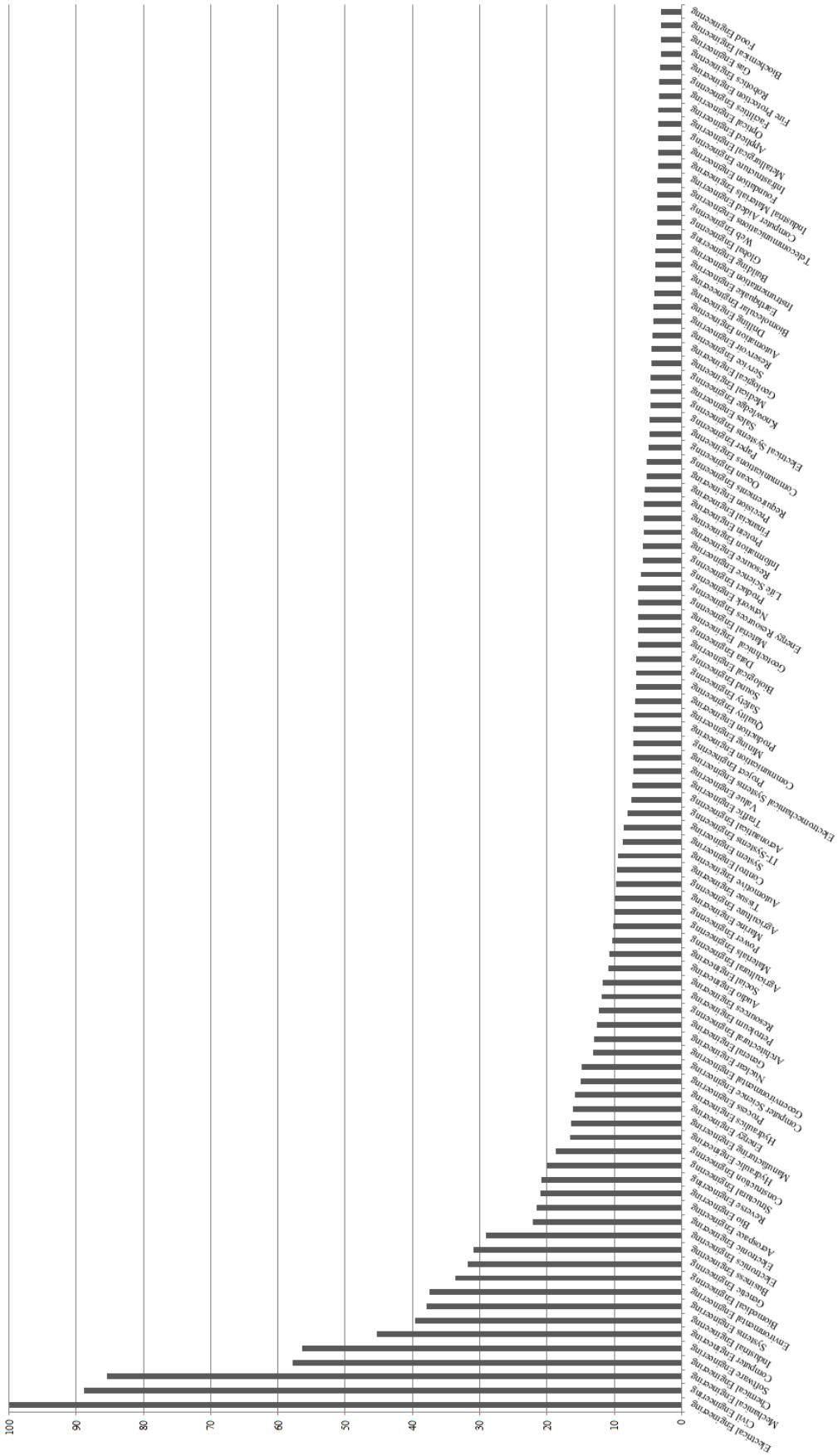

Figure 2: Correlated Internet ranking (top 100)

IV. DESK RESEARCH VS. FREQUENCY ANALYSIS

The correlated top 100 results from Internet search and desk research are shown in TABLE 6. Industrial Engineering, Biomedical, Petroleum and Materials Engineering are not listed in the older linguistic sources (TABLE 4), but they have a high value in newer sources. Software Engineering is an exception with an extraordinary position in Internet ranking and a mean number of mentions in the qualitative sources.

TABLE 6: INTERNET RANKING AND DESK RESEARCH

Discipline	Internet ranking	Three views ranking
Electrical Engineering	1	6
Civil Engineering	2	6
Mechanical Engineering	3	6
Chemical Engineering	4	6
Software Engineering	5	3
Computer Engineering	6	3
Industrial Engineering	7	4
Environmental Engineering	8	5
Systems Engineering	9	2
Biomedical Engineering	11	3
Electronics Engineering	14	4
Petroleum Engineering	31	3
Materials Engineering	36	3

V. LIMITATIONS

The list of engineering disciplines must be considered as incomplete, because there is no full list of engineering disciplines and the evaluation of all hits for "engineering" is not possible. In addition, the disciplines continue to evolve. Moreover, the missing name definition leads to gaps in the research. In several cases it is difficult to decide whether the term is referred to a discipline or not.

Ranking the significance by the number of hits in an internet search engine is not a common research approach and the results must be analyzed carefully. The research was limited to terms matching our name convention. Disciplines named without the term engineering were not considered in the internet analysis. For many disciplines, the number of hits exceeded a million. Because of this high number of results (just the term Engineering has more than a billion hits) it is not possible to check the context of all hits. This could potentially lead to a count of discipline hits when the two words were used next to each other in a different context, e.g. "This is software. Engineering is good". Such failures were not corrected. Because a variance in the number of hits was observed, a set of queries was done in each search engine. But search engine specific inaccuracies, e.g. the rounding of results, could not be avoided. Since the search algorithm is not known, there may be distortions here. In addition, disciplines with relative few hits like "Climate Engineering" (less than 250.000 hits) can be referenced in scientific publications. This phenomenon falsifies the result, but also supports the initial thesis, that there are no rules for naming of engineering disciplines.

VI. CONCLUSION AND OUTLOOK

This work shows six interesting points about engineering disciplines:

1. There is no common naming convention for engineering disciplines.
2. The number of disciplines is undefined.
3. New disciplines are evolving while the significance of older disciplines is changing.
4. Chemical, Civil, Electrical and Mechanical Engineering have a prominent standing.
5. Newer disciplines like Software Engineering, Industrial, Biomedical, Petroleum and Materials Engineering are on advance.
6. Several engineering disciplines have a non-technical background.

It seems that there is no naming convention for engineering disciplines. It is unclear whether Electronic and Electronics Engineering are equal. This is also the case for several other disciplines. Also, the number of engineering disciplines is undefined. As a result of this research a list with more than 200 disciplines was created. The current state of the list of engineering disciplines is published on Research Gate for further suggestions [29]. These two points lead to a lack of transparency and a "jungle of disciplines". A common definition can help for example to compare service offerings. This also includes the comparison of educational programs at universities.

Several publications commit, that there is a hierarchy with Civil, Mechanical, Electrical and Chemical Engineering on top. But it seems that the technological evolvement has a high influence on engineering disciplines. Regarding technology trend forecasts, e.g. biotechnology and energy have a high importance. Information and communications technology and sustainability and environment have a high importance for several years [38]. This is reflected in the evolvement of disciplines and their importance. The top disciplines in the frequency analysis are related to the abovementioned technological fields. Moreover, it is also reasonable to assume that the development of new engineering disciplines and the change of the importance of single disciplines are associated with technological and social development. Therefore, the monitoring of the further development of the disciplines' importance may indicate upcoming technological trends or social changes.

In the historical development of engineering it seems to be plausible that Civil Engineering and Mechanical Engineering were the "first" disciplines. Over the time new disciplines came up and the importance of the different disciplines changed. Interestingly, all disciplines are present in the internet. But the number of hits varies greatly. In this work the number of hits in internet search engines is used as indicator for the importance of disciplines. The hit pattern reflects the technological development and is an indication for the relevance of disciplines. Besides the four old major disciplines

Software Engineering has an outstanding importance. The internet search needs to be tempered with caution as the context of the hits was not tested. But several universities and companies offer Software Engineering as educational program or service. This underlines the importance of the discipline. Another interesting aspect is the increasing incidence of non-technical disciplines. One reason for this could be the increasing complexity of the society and the economy. Engineering can be seen as a buzzword for intellectual services.

This work is a first step towards a better understanding of the diversity of engineering disciplines, the reason for this diversity and the associated problems. Basically, the high number of engineering disciplines is not a problem and the evolvement of new disciplines is necessary to respond to technological development. But a common understanding can create more transparency in this area. Further research about the significance of disciplines, the creation of a general glossary about the scope of engineering disciplines and a common naming scheme are recommended measures.

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