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Towards Building and Sharing a Common Understanding of the Integrated Design Field Evolution

M. Mekhilef	J. Stal le Cardinal	B. Longueville	C. McMahon
Industrial Engineering Department Ecole Centrale Paris – France Mounib.Mekhilef@lgi.ecp.fr	Industrial Engineering Department Ecole Centrale Paris – France Julie.stal-lecardinal@lgi.ecp.fr	EADS Corporate Research Center Knowledge Engineering Department Barthelemy.Longueville@lgi.ecp.fr	Department of Mechanical Engineering University of Bath. UK c.a.mcmahon@bath.ac.uk

ABSTRACT

Questions related to the emergence of new ideas, their density and location may be interesting when trying to understand the evolution of a given field. The design area is an "old" concept that holds many hidden and non-hidden sub-concepts. In this paper we present the latest results obtained from the study of the evolution of ideas in this field based on published material. The question being addressed relates to the positioning of new fields vis-à-vis established topics. To address this question we have considered a subset of international conferences and journals dealing with design and have made a quantitative analysis using keywords. We then study the positioning of a number of concepts and ideas that seem to be interesting in considering international issues in engineering design.

INTRODUCTION

The aim of this paper is the presentation of results obtained from the analysis of papers presented in various conferences related to design. The first focus of this work was on the potential insights that could be obtained from building a dynamic and evolving reference list of keywords in the design field. A fixed list would have the benefit of providing paper authors with a comprehensive set of terms that aims to represent all of the concepts developed in a given area. However, a fixed list has the disadvantage that it fails to represent emerging concepts. Consequently, the challenge is, rather than to try to identify all concepts used, to provide a process that supports the evolution of a key list.

This approach also allows various interrogations that may be of great interest if we can provide answers. Questions such as "Is my paper sufficiently coherent with the focus of a given conference?" or "Is the concept of "Virtual design" still of interest in a given conference?" merit attention and need answers.

We do not claim in this study that we can provide qualitative answers. Instead, we aim to report the results obtained by a quantitative analysis of many conferences. This approach seems to be "naïve"; however, the process is less naïve than one that studies only the keywords given by authors.

A quick look at the literature on design shows that many sub-topics have emerged and others are now emerging. We are convinced that it is now time for a global understanding of the evolution of the related preoccupations in order to start a new phase that gives guidelines on important and emerging issues in design. Many researchers have proposed evolution schemes from an epistemological point of view. However, we still need a pragmatic analysis of what has been done and what is going on now in the various publications that deal with design. The proposed approach described here lies in the systematic analysis of a number of conferences, including the International Design Engineering Technical Conferences (IDETC-ASME)[1], the Design conferences [2], the Integrated Design and Manufacturing in Mechanical Engineering (IDMME) conference [3] and the International Conferences on Engineering Design (ICED) [4]. We also consider the major reviews and journals related to design such as Computer-Aided Design, Journal of Mechanical Design and many others. Our proposition presents a global overview that shows the time-evolution of the topics of the papers in these works, the density of the topics, their geographic evolution and the emerging areas and concepts. We show then that some topics have been of great interest for some time while others are in relative decline.

NOMENCLATURE

The acronyms used for the conferences studied are as follows:

- **CIE:** *Computers & Information in Engineering*
- **DAC:** *Design Automation Conference*
- **DFM:** *Design for Manufacturing*
- **DTM:** *Design Theory and Methodology*

- **ISD:** *Integrated System Design*
- **DETC:** *Design Engineering Technical Conference*
- **PTG:** *Power Transmission & Gearing*
- **MECH:** *Mechanisms & Robotics*
- **IDMME:** *Integrated Design and Manufacturing in Mechanical Engineering*
- **ICED:** *International Conference in Engineering Design*
- **DESIGN:** *Dubrovnik Design Conference*
- **RSAFP:** *Reliability Stress Analysis & Failure Prevention*
- **IIED:** *International Issues in Engineering Design*
- **VIBP:** *Motion & Vibration Control*
- **VIB:** *Mechanical Vibration & Noise*
- **EDC:** *Engineering Design & Control*
- **MOVIC:** *Mechanical Vibration & Noise*
- **EIM:** *Engineering Information Management*
- **FLEX:** *Flexible Assembly*

THE PROTOCOL SCHEME

The early story of this study started with the question: ***what are the emerging concepts in design?*** To answer this question we have selected a set of international conferences (see the nomenclature) which we attend regularly. We have started the identification process by building a subset of keywords starting from our background knowledge. The list is shown in Table 1. We have then addressed the main international journals dealing with design. The examination of the papers that refer to design and use some emerging concepts such as "knowledge management in design", "sustainable design" and so on shows that not all the inputs come from mechanical engineering. In fact, design is not specific to this area and other disciplines have provided many inputs.

The second stage of our approach was to ask: ***what are the keywords the authors suggest for their papers in design?*** To answer this question, we tried to extract the information from on-line copies of papers to which we had access. However, the main on-line servers do not provide such information. We then oriented our search (under the hypothesis that the keywords suggested for journals are in some way the same as those suggested for international conferences) to the conferences that ask for a list of keywords after the abstracts, including the ICED and DESIGN conferences.

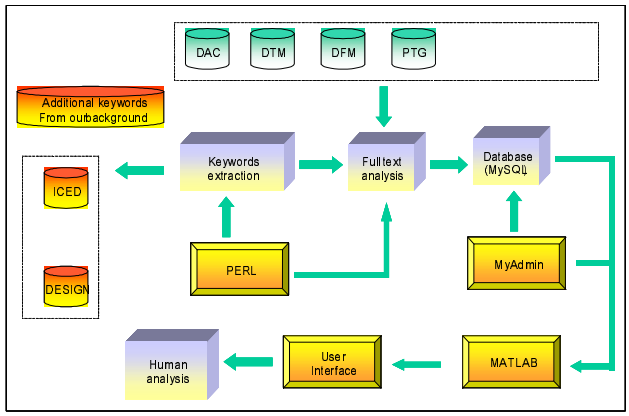

Figure 1. The process used to extract the concepts.

Figure 1 shows the whole process we built for this study, showing the position of keyword extraction. Using a set of scripts written in Perl, we extracted all the keywords used by the authors in the headers of their papers, where this information was available. The resulting list included about 3000 syntactically different key terms: words (product, decision,…) or associations of words (axiomatic design, knowledge management,…). A clean-up process has been followed in order to merge the terms that deal with the same concept. The final consolidated list includes now 2300 terms. It is important to maintain and update this list in order to keep track of emerging areas and concepts.

Concept	Conf	Jour	Concept	Conf	Jour
Systematic Design	24	7	Automatic Design	56	7
Ecological Design	7	2	Engineering Design	729	117
Concurrent Engineering	130	129	Assembly Design	227	11
Sustainable Design	25	0	Robust Design	718	21
Design for Assembly	190	20	Design for Manufacturing	1205	6
Design for X	127	5	Design to Cost	15	10
Product Design	325	111	Advanced Design	43	1
Design Assembly	0	8	Optimal Design	562	88
Rational Design	64	1	Perceptual Design	125	0
Integrated Design	454	22	Virtual Design	200	8
Product Development	366	109	Uncertainty	39	719
Collaborative Design	142	59	Distributed Design	340	10

Table 1. Comparison of occurrences of pre-defined concepts in international journals and conferences

The next step focused on the extraction and detection of the identified concepts within the other conferences that do not include a keywords section in the header of the papers. A full text analysis has been done and data collected. Each paper of each conference was parsed in order to calculate the occurrence of each keyword identified in our list.

Quantitative Analysis

For the quantitative analysis of the papers, four ratios have been defined. The first, R1, makes a correction to the number of papers where a keyword has been found. It is defined by:

$$R1 = Noc * Nbp / NbpT \quad (1)$$

Where :

- Noc= Number of occurrences of a given concept in the whole list of papers of a conference;
- Nbp= Number of papers where the given concept has been cited.
- NbpT= Number of papers presented within a conference.

In fact this number, considered alone, may differ slightly from one conference to another. More precisely, if a given conference holds more papers than another (owing to a large number of parallel sessions for example) then Noc may be very large. Consequently, R1 is more significant than Noc. This ratio has been used to filter the papers in order to consider only those dealing really with the concept attached to the keyword.
The second ratio, R2, has been used to study the place of a keyword (and so the related concept or research area) within a conference. It is defined using:

$$R2=Noc/NbpT \quad (2)$$

In some cases, we can find a small number of papers dealing with a specific concept without being considered in a conference by the allocation of a slot or session. R2 help us to study how an area is considered in a conference.
The third ratio, R3, is another way to filter the papers that deal with a concept. It is defined by:

$$R3=Noc/Nbp \quad (3)$$

In practice, we have ignored those papers that record less than 4 occurrences of a keyword (i.e. Noc<4). This number has been chosen because some fields (title, abstract, keywords, references) may contain the keyword while the text does not.
The fourth ratio used is R4, which helps to identify whether a conference consider an area of research or not. This relative number has been used for some plots in order to bring a "qualitative" appreciation of the results. It is defined by:

$$R4=Nbp/Nbpt \quad (4)$$

There exist other ratios that could be used, but R4 is the one we have preferred since it represents two ideas. Firstly, we need to avoid considering concepts that are only occasionally used, even if they may be used in different papers. Some authors make references to some ideas without using them in the core of the text. Secondly, we needed also to distinguish a paper that is deeply focused on an idea but remains isolated among the other papers of a conference. This situation may point the fact that a new idea is emerging and we have to track this kind of knowledge.
Overall, two levels of study may be performed. The first is to analyze the outcomes from the conference point of view so that we can understand the evolution of the topics. The second is to track new ideas (isolated concepts) in a conference and to correlate them to those emerging in other conferences.
Note that in this study, different levels of interpretation of the results have been achieved. Obviously, terms such as "design", "function" or "model" occur so frequently that in terms of the investigation they do not provide any significant outcomes. We have in general ignored those terms that we consider less informative in this way, although they are still shown in the figures in the next section.

RESULTS AND DISCUSSION

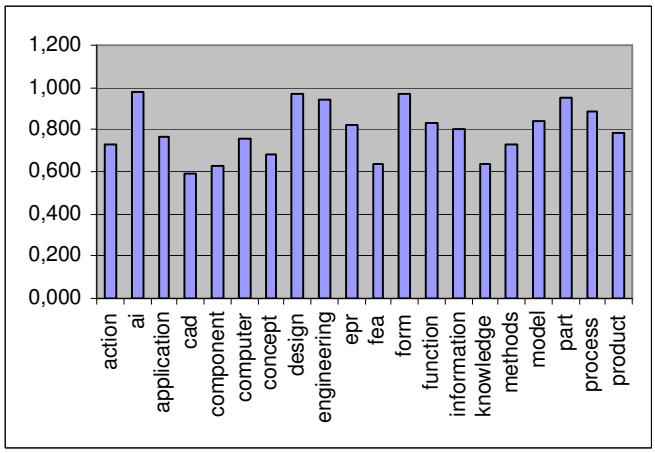

Figure 2. The top 20 generic terms

The first result that may be reported is the fact that there are 300 different terms that are used explicitly by a large number of authors in all the considered conferences. In Figure 2 we have reported the top 20 terms from this list (where ai= artificial intelligence, fea= finite element analysis and epr= enterprise process reengineering). The selection has been done using the ratio (R4) that represents the relative importance of the concept within the conferences.
The main work in this set of conferences is related to solving engineering problems arising in engineering companies related to the design aspect. Almost all the papers present solutions based on computer applications. The approaches deal with both product and processes. This illustrates that integration is now a fact and not more an objective.
Given this general signature of the selected conferences, let us browse them and check the concepts used by the authors and make a comparison between the conferences. The aim of this proposition is to study the "specific signature", if any, of each event.

The CIE Conference

The Computers and Information in Engineering conferences led to 617 papers in our records. Figure 3 shows that the papers dealing with artificial intelligence are of great interest (many other highly rated terms are very common and thus not very informative). The same conclusion may be made for the others terms – for example consider the position of "computer", "structure" and "FEA". Curiously, the design concepts and the user requirements do not appear as important.

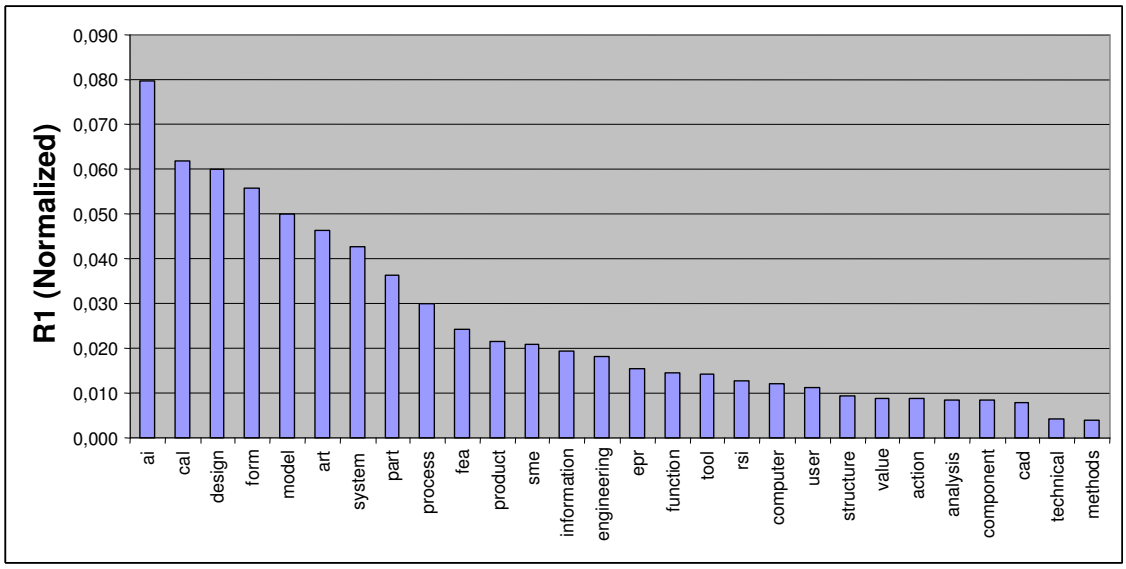

Figure 3. Signature of the Computers and Information in Engineering Conference.

On another hand, there are a plenty of new concepts that are emerging (Figure 4). For this conference virtual tools, globalisation and communities of practice seem, for example, to be considered more and more. Note that one has to understand the idea of "emerging concepts" as those concepts that are new for a given conference. Some of them may be completely new, but others new only for the community that publishes in a given conference.

The DESIGN Conference

The DESIGN conference, that is sponsored by the Design

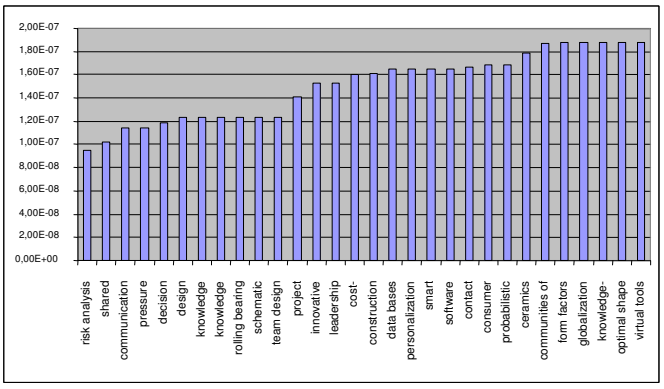

Figure 4. Some emerging concepts within CIE

Society, is held every two years alternating with the ICED conferences. The event is organized by the University of Zagreb and is becoming now a regular place where researchers meet on various fields of design.

Figure 5 shows the main terms used in the DESIGN conference. We can notice that Artificial Intelligence is present at the top level. This might be explained by the fact that the papers include references to journals and conferences concerned with artificial intelligence in design. At a second level we can claim that this conference is in harmony with its objectives since the "design" concept is present at a high level. The conference deals with products and processes. Tools and concepts, information and knowledge occur at similar levels. From this point of view there is an equilibrium in this conference. This equilibrium indicates the ideas widely used. If we turn now to the emerging concepts we find that crack propagation, VRML, eco-design, innovation process, decision-making, knowledge management, design information system, multi-disciplinary aspects and many other items are still at their early stage while they are already significant for other conferences such as DAC.

The Design Automation Conference

The Design Automation event (DAC) will celebrate its thirtieth

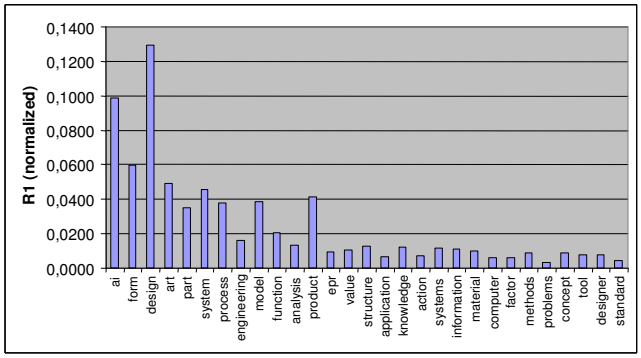

Figure 5. The DESIGN conference shares many topics with the CIE conference

birthday this year. This is a regular conference and it is interesting to study its positioning as well as the evolution of the ideas submitted here. While we compare with the general behavior of the selected conferences, one can see from Figure 6 that the topics are homogeneous. We can also notice that it is the best place for talking about "optimization in design" and a classical (traditional) place for engineering problems such as finite element analysis. It is also a place where rising concepts are accepted. In this area we notice the presence of papers related to information, knowledge and design concepts.

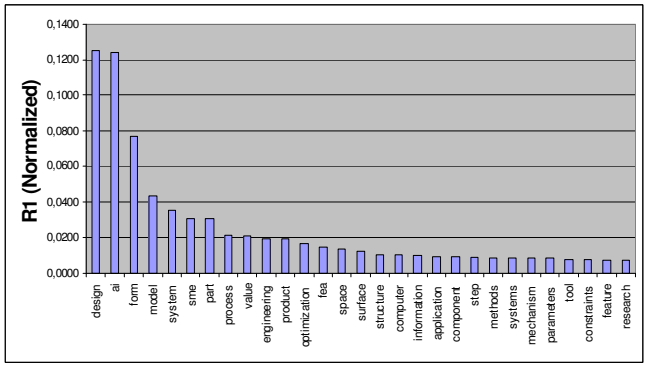

Figure 6. The most used terms within DAC classified using ratio R1

The ICED Conference

The International Conference on Engineering Design (Figure 7) appears as a homogeneous place for design fields. We may characterize it by noting that aspects related to the knowledge used in design from the point of view of the designer, design management and the information systems are welcomed. Another interesting aspect is that project, process and product are considered with the same importance. This ensures that new approaches in design, that take into account many aspects including technological, human and organizational are embraced.

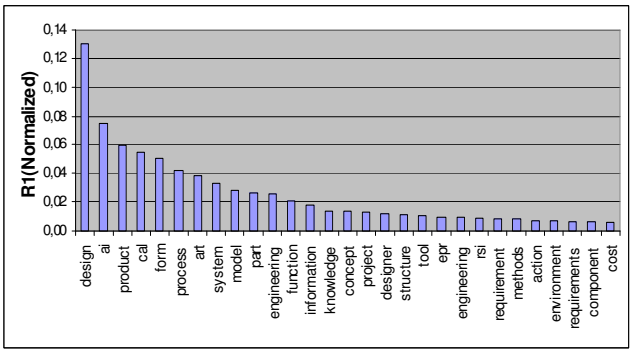

Figure 7. Distribution of the most used terms wihin the ICED Conference

We can see from Figure 7 that environment is already an important term in ICED conferences. Some interesting new concepts are gaining ground, such as eco-efficiency, design co-ordination, value chain, knowledge support, critical situation, eco-design, mechatronic systems, tacit knowledge and many others.

THE DFM Conference

The Design for Manufacturing Conference (Figure 8) gives a rising place to computer applications. The studies presented focus on product and process development but as noted these are also discussed in other places. Owing to the nature of the conference, issues such as manufacturing, features, surfaces, assemblies, components and form are naturally of significant interest. However one can notice the absence of knowledge management and the related areas. This may be due to the "hard" engineering field that gave emergence for this event. Figure 8 does not show any special interest in new ideas among the most used concepts.

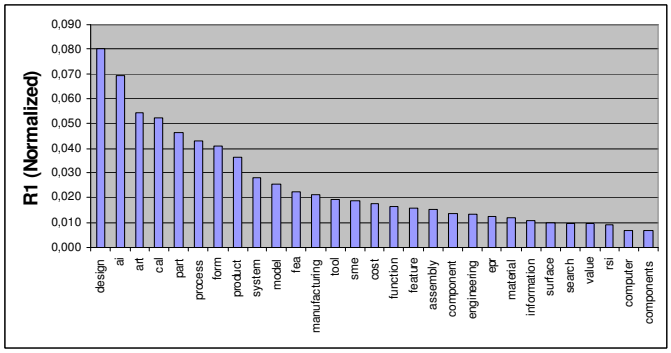

Figure 8. Most used concepts within DFM.

Nevertheless, a more specific study shows that the concepts that have been emerging in DFM during recent years vary from the concept side to the tools side. They include: design concepts, case-based reasoning, genetic algorithms, product families, design knowledge, early stages of design, cost analysis, engineering management, detail design, concept design, functional decomposition, information systems, product variety and process models.

THE IDMME Conference

The results for the IDMME (Integrated Design and Manufacturing in Mechanical Engineering) conference, organized by the French AIP-PRIMECA group of more than 13 engineering school and universities working in mechanical engineering are shown in Figure 9. Note that these results are for one conference only, and that design is only one aspect of this conference. Consequently, the distribution of the most used concepts differs slightly from other events. The fact that more than 30% of the total keywords are used only by these authors indicates that the community for this conference is (for the year studied) rather different than for the others. We are aware that this is changing, and in fact this years conference, held in Bath, enlarged the IDMME community.

Since the IDMME is a young conference it can be seen that it hosts all the new-coming concepts without any constraint. This is one of the benefit of the early stages of an event.

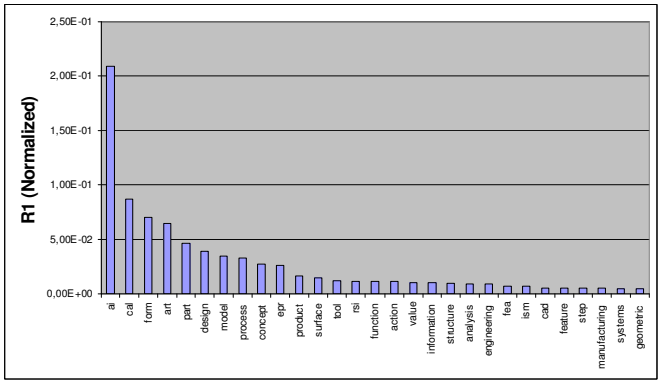

Figure 9. Most used concepts within IDMME.

TRANSVERSE STUDY

In addition to studying the overall allocation of topics in a conference, it is also possible to focus on a set of pre-defined concepts. This is what has been done with the list of terms concerned with interesting fields in design presented in Table 2.

In the study, we tried to identify the best conferences at which to present particular topics. From this work, it is now possible to answer specific questions such as "Does my paper fit with this conference?". Space does not permit the work on each term to be presented, but we consider below a number of examples to illustrate the approach.

Concepts	Concepts
Distributed design	Defective design
Eco-Design	Creative design
Automatic design	Aesthetic design
Adaptive design	Design education
Advanced design	Design abstraction
Axiomatic design	Design cognition
Collaborative design	Decision-based design
Cost-oriented design	Collective Design
Conceptual design	Design Ethics
Constraint-based design	Architectural design

Table 2 Subset of predefined concepts

Aesthetic Design

If we consider "Aesthetic Design", Figure 10 shows that there is not a single best place where we should discuss this topic among the studied conferences. In fact, CIE, DAC, DESIGN, DTM and ICED are equivalent places at the present moment. It is interesting to notice that ICED is giving less emphasis to this area – the topic is more the preserve of the industrial and product design fields – while CIE is perhaps hosting an increasing number of papers to the fields of aesthetic design. The study did not show the IDMME, DFM, IIED and other conferences (not mentioned above) publishing papers on the topic.

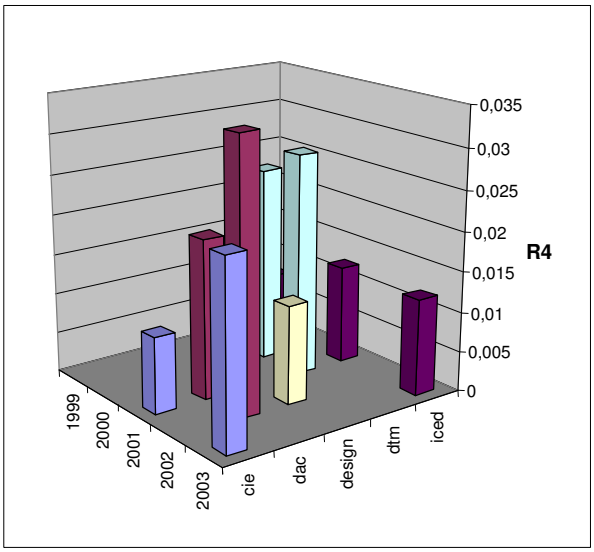

Figure 10. Aesthetic Design is just emerging

Automatic Design

When we consider the "Automatic Design" topic, Figure 11 shows that there are regular places such as the DAC and CIE conferences that host the related papers. However we also noticed that this regularity doesn't mean increasing interest. Is it a matter of consideration by the organization committees? Or

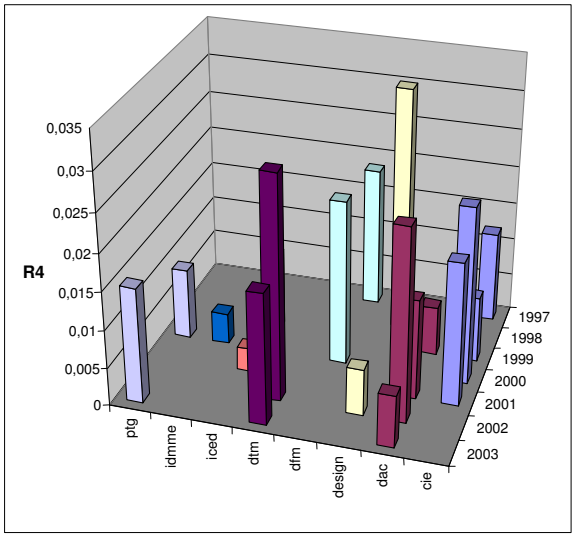

Figure 11. Distribution of the Automatic Design.

is it simply a dying concept? To answer these kinds of questions, one has to compare publication in conferences with that in journals. If a concept has been widely covered during a certain period in international journals then it may be understood as a mature concept. By contrast, if the concept has not been considered in journals then perhaps it may be understood as a dying concept, at least during this period.

Axiomatic Design

Axiomatic Design (Figure 12) is naturally more theoretical and thus should be hosted by a specific conference. This is the case with the DTM conferences. One can notice that the competition in this area is very low, and thus the DTM is the natural place for this topic. The distribution of papers shown in Figure 12 may also suggest that interest in this topic has peaked and is not slightly in decline. Conversely, the interest in the topic is increasing in the ICED community, perhaps reflecting a greater internationalization of that community.

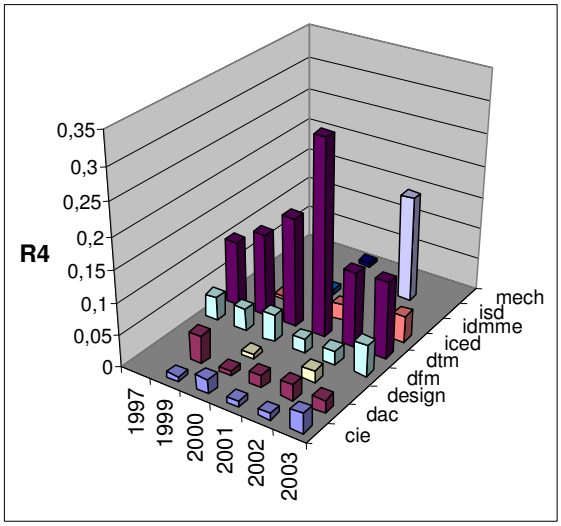

Figure 12. Distribution of the Axiomatic Design concept

Creative Design

A more generic field, represented in Figure 13, is "Creative Design". The figure shows that the topic is a central concern of the DTM conferences, and also of significant interest in ICED and EDC conferences. Note that the R4 ratio shows relative emphasis in each conference. For a large event such as ICED, a lower R4 score may mask the fact that there are a large number of papers on the topic.

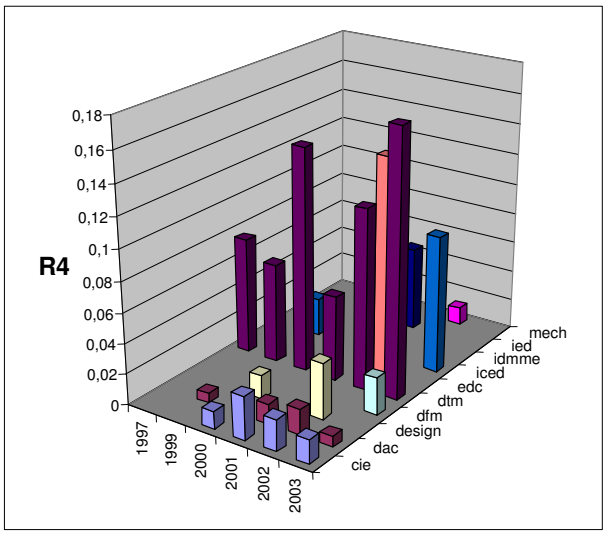

Figure 13. Creative Design concept distribution.

Decision-based Design

Figure 14 shows the distribution of the papers related to "decision-based design". One again, there is a strong interest in this topic in the DTM community, with smaller but nevertheless significant interest in CIE and DAC. However, the topic has a very low rating in the ICED conference. These results perhaps reflect a strong interest in the topic concentrated in the North American research community.

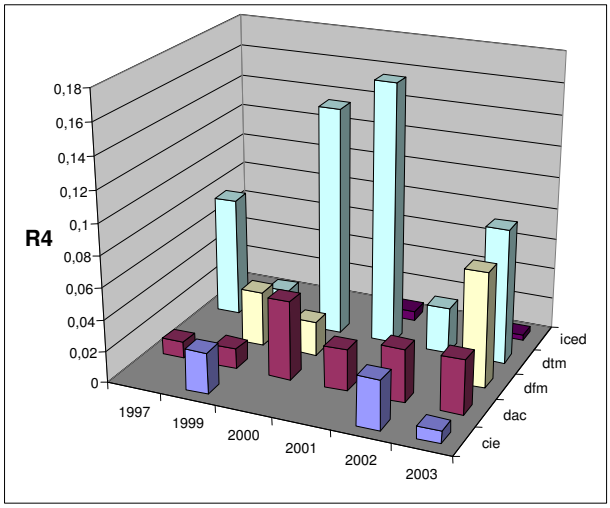

Figure 14. Decision-Based Design concept distribution.

Design Education

Finally, "Design Education" (Figure 15) is also present at all the events. But it may be noted that it was a particular focus of the International Issues in Engineering Design Symposium in 2001, and the formation of the Design Society Special Interest Group in Design Education (DESIG) will provide a specialist home for this topic in the future.

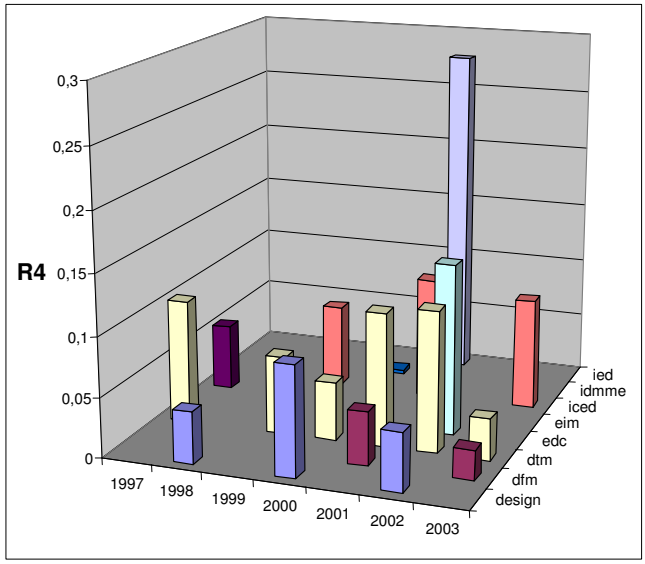

Figure 15. Design Education is covered everywhere

AUTOMATIC CLASSIFICATION

Because a study that deals only with one keyword/concept at each stage is not sufficient, we tried to consider all the possible combinations in order to extract more valuable results. To do so, we have successively applied two algorithms for classification. The first is the Principal Component Analysis approach that allows the handling of non-numerical data and secondly the K-mins algorithm that builds categories by means of a numerical distance that uses the frequency of a term in a paper and the volume of papers that include a keyword.

Twenty classes have been obtained in this way. It is not possible in the frame of this paper to give all the results, however we report here the results obtained for class 19. Table 2 shows the keywords from that class that reach the threshold of 2.0 used by statisticians to consider a class as characteristic and discriminating.

```
CLASSE  19/ 20
Number of elements:   13
-----------------------------------------+
|RG | DISTANCE  | IDENT.
+---+-----------+------------------------+
|  1|    0.87396|product development
|  2|    1.34102|assembly
|  3|    1.74914|simulation
|  4|    2.17706|design process
|  5|    2.17706|experience
|  6|    3.34222|constraints
|  7|    3.62510|interface
|  8|    3.69232|methodology
|  9|    4.09957|communication
| 10|    4.14243|comparison
+---+-----------+------------------------+
```

Table 3. Components of class 19.

Figure 16 shows the evolution of the number of papers dealing with each term from Table 3. One can see that there is a broadly common behavior between the concepts that define this class. We can also conclude that the research dealing with the material addressed by this class is in a positive evolution.

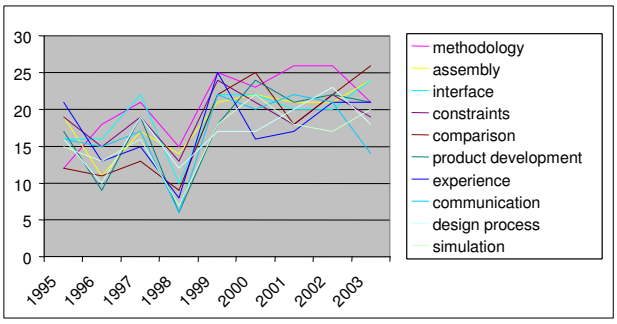

Figure 16. Behavior of class 19 (as an example)

Class number 19 defines the keywords that are evolving in the same way. There is not necessarily a semantic connection between the elements. This might indicate that we need to look deeply for the possible links between the concepts in each of the 20 classes. This has to be done by means of a semantic analysis through the building of an ontology, which is not currently our purpose. For a more in depth investigation, Table 4 shows that the occurrence of the variable in the class is very high (second and fourth column) while at the same time this is not the case if we consider the whole sample (column 3), confirming the discriminating power of the class. The fifth columns show the number of classes that share the same occurrences within the whole sample. Test-value is the combination of the three values used for statistical purposes to define a characterizing and discriminating class (where a high value is a positive indication).

CONCLUSION

We have presented in this study a set of the first results obtained by the quantitative analysis of the terms used in various conferences related to design. The approach followed has the disadvantage of considering only the syntactic aspects of the terms.

We have shown that it is possible to build a process that delivers the keyword list for any conference. We note that the importance is not simply to build a list of keywords that becomes a reference for the authors as this has already been done in various areas, but rather to build a process that updates a list of keyword, in order to keep the list open for new upcoming ideas.

There are a number of respects in which we must be cautious:

- It is not that easy to get an understanding on what is going on within a given community without appearing at least as "conceited"!
- A given concept may be addressed with other terms other than those that have been identified and may thus appear as absent although it is present.
- The study we are developing here does not take into account papers submitted to a conference but rejected.

The process we presented here is at its early stage and the beginning of its history. This study will be improved with specific algorithms in the near future, taking into account the limitations we mentioned above and other existing approaches that might be useful for this kind of research.

The understanding of the emergence of a new concept is an important issue to concentrate on in the future. We wish to explore if there is any relation between the disappearance of an idea and the birth of a new one? And thus does the interpretation of these effects have the same difficulty? Are we able to build *a priori* studies ? All these questions remain open and merit investigation.

Finally, merging this approach into a semantic, ontology-based one may lead to a better understanding and thus a better scheduling of forthcoming events.

Class: CLASSE 19 / 20

Variables	significant occurrence	% occurrence in the sample	% occurrence in the class	% of the class in the occurence	Test-Value
1999	Very frequent	4,6	100,0	54,2	9,0
2002	Very frequent	4,8	92,3	48,0	8,2
2001	Very frequent	3,8	84,6	55,0	8,0
1997	Very frequent	3,8	76,9	50,0	7,3
2000	Very frequent	5,0	76,9	38,5	6,9
1995	Very frequent	3,4	69,2	50,0	6,8
2004	Very frequent	3,4	61,5	44,4	6,1
1998	frequent	4,0	61,5	38,1	5,9
2003	Very frequent	3,1	53,8	43,8	5,6
1996	frequent	5,4	61,5	28,6	5,4
1996	Very frequent	3,1	38,5	31,3	4,2
2003	Very very frequent	4,4	38,5	21,7	3,7
2004	frequent	5,0	38,5	19,2	3,5
1995	frequent	5,4	30,8	14,3	2,7

Table 4. Statistical outputs for class 19.

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