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Review Article

FEM and BEM in the context of information retrieval ☆

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Abstract

Numerical techniques such as, first of all, the finite element and boundary element methods are frequently used today in research as well as in many industry applications. The output of finite element and boundary element literature and development of software, has been growing during last three decades. Today, it is almost impossible to be up-to-date with all the relevant information. At present, we have an excess of information—the term "information fatigue syndrome" will soon be a recognized medical condition. The author presents, by means of information from his database, the progress of both numerical techniques in their theoretical developments and practical usage for the period of last 30 years. The topics included: finite element and boundary element literature and software with emphasis on structural and solid mechanics. Some pointers for classical, printed, and for modern, on-line, information retrieval are given.

1. Introduction

Science today is a crucial and expensive part of human activity. Available information and an effective access to it plays in this context a very important role. It is a well-known fact that the information is the most valuable, but least valued, tool the researcher has. The output of scientific papers in journals or conference proceedings is growing fast and professionals are no longer able to be fully up-to-date with all the relevant information. The increasing specialization in science and technology has resulted in the proliferation of subject-oriented journals as well as conference proceedings directed to specialist audiences. This means that professionals have more channels for communicating the results of their research at their disposal, but on the other hand to find requested information may be a more time consuming and uneasy process than some decades ago. It is also questionable if researchers are willing to spend their working time for looking for information. It has been pointed out that in engineering, informal channels are the most frequently used means of obtaining information. Many professionals prefer to rely on personal judgment or on the wisdom of their colleagues whenever they have problems to solve. The "do-it-yourself" syndrome, manifested by the professional loners, was also believed to have perturbing results—missing out on vital relevant information and acquiring inaccurate or inadequate information.

The main problem in information retrieval is that the output of printed scientific literature tends to double within a period of 10–15 years; on-line information output is presently doubling every four years, and it is supposed that by the year 2000 it will be doubling in one year's time.

First, let us look on how the information sources are classified. Roughly speaking, there are "classical"-printed and on-line information sources. The printed information sources can be divided into three categories. The primary, and the most important source, are original reports in form of books, journal papers, conference papers, theses and dissertations, internal reports, etc. Information in all of these sources is scattered and

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unorganized and the information retrieval is difficult. The secondary information sources are compiled from the primary ones and are arranged according to some type of classification or indexing, so the orientation in information retrieval is easier. The abstract journals and reference books are typical examples from this category. The last group, tertiary sources, can be characterized as sources of information on the secondary documents, for example bibliography on bibliographies, directory to databases, etc.

During last few years the on-line information search in databases, or on the Internet has been taken for granted. The Internet, particularly its collection of multimedia resources, the World Wide Web (www) has been named as the world's library for the digital age. In fact, it is a chaotic collection of information for non-linear reading, growing too fast. The search mechanisms available on the www are catalogues or search engines, respectively. The catalogues give a hierarchical ordering of www pages and are useful for looking for information on general topics. The search engines work by looking for matches between words in a query and words in the indexed www pages.

Many professionals are starting to suffer from information overload. The "information fatigue syndrome" that will soon be a recognized medical condition has symptoms including tension, occasional irritability and frequent feelings of helplessness. The irony of circumstances is the fact that published information very often contains repeated information. It is estimated that only 10–20% of it present new, unknown approaches.

The emphasis of this contribution is to investigate the status of information dealing with the finite element (FEM) and boundary element methods (BEM) in a form of bibliometric studies. Bibliometric analysis has become a well establish part of information research and a quantitative approach to the description of documents. It can be applied to any subject area and to most problems concerned with written communication. In other words, we can say that bibliometrics is the statistical or quantitative description of literature. The history and recent developments in FEM and BEM computational technology will be summarized in connection to available information. The following topics will be handled:

- FEM and BEM literature (books, journals, conference proceedings in a "classical"-printed form, and information available on www),
- FEM and BEM software (general and special-purpose programs).

Most of presented figures are based on information retrieved from the author's database, MAKEBASE. MAKEBASE is an integrated database composed of two distinct parts: literature references and software information, respectively. The subjects include: FEM, BEM, and design optimization. At present this database contains more than 121,000 literature references and information about 1700 FEM and BEM programs [1]. The database is updated on a daily basis with annually addition of ≈7000–8000 references.

It is not the author's intention to draw any conclusions. To give a view of the future of FEM or BEM is an extremely difficult and uncertain task, therefore this presentation should be considered as an example of a different usage of a database dealing with numerical methods. A review of some recent advances in the computational structures technology with a look to the future can be found in [2].

This paper contains two main parts: finite element and boundary element literature, and finite element and boundary element software, respectively.

2. Finite element and boundary element literature

The information sources handled in this section include: books, journals and conference proceedings.

BEM and especially FEM are powerful numerical methods becoming as the prevalent techniques used for analyzing physical phenomena in the field of structural, solid, and fluid mechanics. Also coupled problems (thermomechanical, fluid–structure, soil–structure), simulation of various processes in engineering, geomechanics, biomechanics and biomedicine, and other fields of science can be studied by both techniques in a way that no other tools could accomplish.

2.1. Books

The pioneering works on FEMs started in the early 1960s at the University of California, Berkeley, and at the University of Wales, Swansea. Other activities have been carried out at the MIT, Cambridge, MA and at the University of Stuttgart, Germany. Well-known names of the pioneers from this time are R.W. Clough, E.L. Wilson, K.J. Bathe, J.H. Argyris, O.C. Zienkiewicz and others. The first book on the subject was published in 1967, written by Zienkiewicz and Cheung [3].

Between 1967 and 1999 467 book titles on FEM have been published. An incomplete list of these books with abstracts and other bibliographical data can be found in [4] or on the web as an up-to-date version, developed by the author of this paper, with URL address: http://www.solid.ikp.liu.se/fe/index.html.

The first works on BEMs can be dated back to the 1960s (Jaswon, Hess, Symm, etc.), developed for the solution of certain fluid and potential problems. Later, a small group of researchers at the Southampton University, UK, started working on applications of BEM to the stress analysis problems. An increasing activity in a modern BEM research has been delayed to the middle of the 1970s. The first book on BEM was written by Brebbia and published in 1978 [5].

Between 1978 and 1999, 223 book titles on BEM have been published. Their not-up-to-date listing with a short abstract can be found in [6]. Web presentations of some of these books can be found at URL address: http://www.boundary-element-method.co.uk; or http://www.olemiss.edu/sciencenet/benet.

2.2. Journals

Journals are the most frequently used and the most important information sources for professionals. Their advantages over the books are: a frequency of publication; they are more up-to-date than information appearing in books; and a small number of "core" journals for each subject can be selected. The disadvantages: delay between research progress and publication; proliferation of subject-oriented journals directed to specialist audiences; a number and a cost of technical journals is rapidly growing.

Information about published papers can be found in abstract journals (e.g. Applied Mechanics Reviews), online presentations and databases. The electronic platform of on-line databases usually contains abstracts and index terms to articles published worldwide in all fields of engineering, medicine, physics, etc. These databases are more or less directed to a specific field of interest. To name some of the well-known databases covering fields of engineering: COMPENDEX, INSPEC, METADEX, and others. Many publishers present their journals in a paper- and on-line versions, where both contents and full-text information in an electronic access is available (in PDF or HTML format). Unfortunately, only customers holding full rate subscriptions are entitled to activate on-line access to the full text of those journals. The free-of-charge alert services for readers are also offered by many publishers (e.g. Contents Direct). Table 1 lists the most important journals available on-line in the field of structural mechanics and materials engineering where papers dealing with FEM and BEM are frequently published.

There are also various societies and professional institutions in USA, UK, Japan, China and other countries publishing own journals that should be mentioned. To give some examples:

- The American Society of Mechanical Engineers (ASME) publishes 18 titles, for example Journal of Applied Mechanics, Journal of Engineering Materials and Technology, Journal of Vibration and Acoustics, Journal of Biomechanical Engineering, etc. For more information and online access: www.asme. org.
- The American Society of Civil Engineers (ASCE) publishes 30 titles, for example Journal of Engineering Mechanics, Journal of Structural Engineering, Journal of Bridge Engineering, Journal of Computing in Civil Engineering, etc. For more information and online access: www.asce.org.
- The American Institute of Aeronautics and Astronautics (AIAA) publishes six journals. For more information and online access: www.aiaa.org.
- The Professional Engineering Publishing in UK publishes Proceedings of the Institution of Mechanical Engineers (www.imeche.org.uk), Part A–Part M; Thomas Telford in UK publishes the complete proceedings of the Institution of Civil Engineers (www.ice.org.uk).
- JSME International Journal (series A, B and C, English edition) is the source for Japanese and worldwide mechanical engineering research (www.jsme.or.jp).
- Finally, two journals not mentioned earlier but often cited: Structural Engineering and Mechanics (technop.kaist.ac.kr) and Journal of Strain Analysis for Engineering Design (www.pepublishing.com).

An interesting project under progress started at Elsevier and is called The ScienceDirect Gateway. The developed technology enables linking between primary and secondary content between electronic distribution platforms. Gateway partners include BioMedNet, Engineering Information, MDL Inc., Academic Press, the American Institute of Physics, and the CrossRef organization. The CrossRef will establish common linking protocols between research journals and secondary databases by enabling links from citations and abstracts to the full text of the article. It will enhance the efficiency of browsing and reading the primary scientific and textbook literature.

The state of published literature for FEM and BEM is illustrated in Fig. 1 as a function of time. This figure represents the number of published papers, including books, on the subjects during almost all time of their existence. The number of references between 1965 and 1975 is taken from [7], and those for the period 1976–2000 from the author's database. The year of 2000 in this figure is not quite relevant because MAKEBASE is for this year still under updating. Fluid mechanics problems for FEM are not included.

At present, as it can be seen from Fig. 1, about 7000 papers on FEM and 800 papers on BEM are published annually. The output of FEM literature has an exponential growth to 1994, then continue to grow slowly and is almost constant. The output of BEM literature is roughly one sixth of FEM literature; it grows slowly and during last ten years is also almost constant. FE and BE

Table 1
On-line journals for structural mechanics and materials engineering

Publisher	Service	URL address	Journal name
Academic Press	IDEAL	www.idealibrary.com	J. Sound Vibr.
Elsevier	ScienceDirect	www.elsevier.nl	Acta Mater. Adv. Eng. Software Appl. Math. Modell. Compos. Struct. Compos. A, B Compos. Sci. Technol. Comput. Mater. Sci. Comput. Meth. Appl. Mech. Eng. Comput. Struct. Eng. Anal. Boundary Elements Eng. Failure Anal. Eng. Fract. Mech. Eng. Struct. Eur. J. Mech. A, B Finite Elements Anal. Des. Int. J. Mech. Sci. Int. J. Solids Struct. Int. J. Impact Eng. Int. J. Fatigue Int. J. Plast. Int. J. Non-Linear Mech. J. Constr. Steel Res. J. Mater. Process. Technol. J. Mech. Phys. Solids Mater. Sci. Eng. A, B Mech. Mater. Mech. Res. Commun. Nucl. Eng. Des. Probab. Eng. Mech. Struct. Safety Theor. Appl. Fract. Mech. Thin-Walled Struct.
IoP Publishing	Electronic J.	www.iop.org/EJ	Smart Mater. Struct.
Kluwer Academic Publishing	Kluwer Online	www.wkap.nl	Appl. Compos. Mater. Int. J. Fract. Meccanica Mech. Compos. Mater.
MCB University Press	Emerald Library	www.mcb.co.uk/portfolio.htm	Eng. Computations Int. J. Num. Meth. Heat Fluid Flow
Springer Verlag	LINK	link.springer.de/ol/eol/index.htm	Arch. Appl. Mech. Comput. Mech. Eng. Computers
J. Wiley & Sons	Interscience	www.interscience.wiley.com	Communicat. Numer. Meth. Eng. Int. J. Numer. Meth. Eng. Mech. Cohes.-Frict. Mater. Progress Struct. Eng. Mater.

papers illustrated in Fig. 1 have been selected from more than 1600 journals and new journals are appearing each year.

Finite element and boundary element techniques have been successfully used as analytical tools in many engineering areas, not only in structural mechanics.

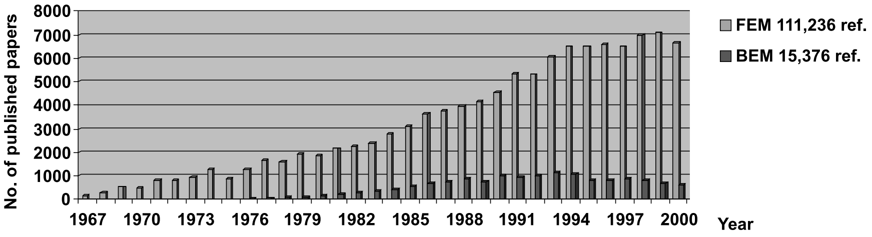

Fig. 1. Chronological distribution of FE and BE papers (1965–2000).

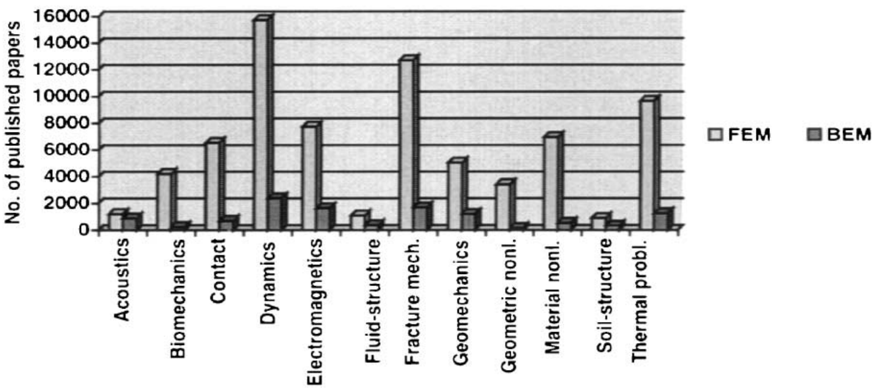

Fig. 2. FE and BE papers for various topics (1976–1999).

Fig. 2 illustrates the total number of FEM and BEM papers for various topics that were published between 1976 and 1999. Types of papers included are journal papers, conference papers, and theses/dissertations. The author is, of course, aware that many papers are missing (hopefully, not more than 20%). Papers in Fig. 2 are grouped according to topics into the following categories: acoustics; biomechanics; contact problems; dynamics; electromagnetics; fluid–structure interaction; fracture mechanics; geomechanics; geometric-non-linear problems; material-non-linear problems; soil–structure interaction; and thermal problems. From this figure it can be seen that the main research FE activity has been directed to the solution of dynamic, fracture mechanics and thermal problems. Many of BE papers deal with dynamic, electromagnetic and fracture mechanics problems.

Fig. 3 shows FE and BE analyses and simulations used for various engineering materials and structures such as: aluminum; ceramic/glass; composites; concrete;

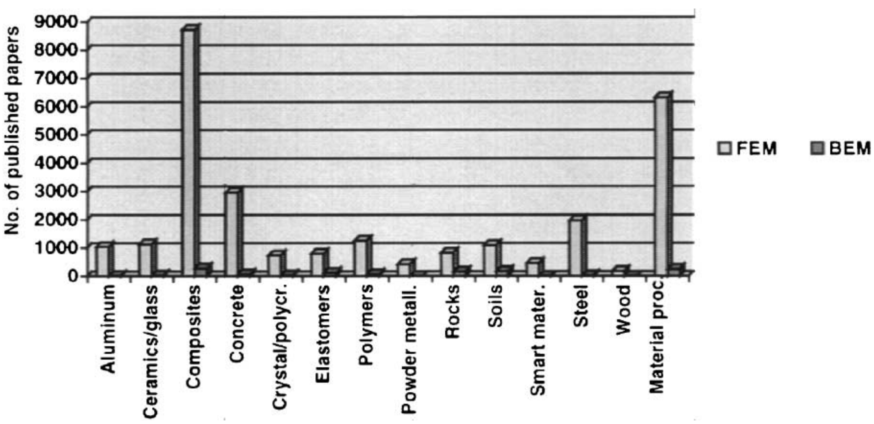

Fig. 3. FE and BE papers directed to various materials (1976–1999).

crystals and polycrystals; elastomers; polymers; sintered powder materials; rocks; soils; smart materials; steel; and wood. The simulations of material processing is also included in this figure.

Fig. 3 shows that most computations/simulations are focused on the development of computational models for composite materials where noteworthy contributions are directed to the development of new composite finite elements, determination of interlaminar stresses, delamination studies, heat transfer analyses, and study of buckling and postbuckling, as well as impact problems. Macromechanical and micromechanical models have been developed. Not many BE papers are directed to the analysis of specific materials. Results from the computations can give material developers help for improving material systems and thereby meet performance and design requirements.

If we are looking on the number of published papers in each specific category for each year between, for example, 1986 and 1999, then we can see the increase or decrease in the development effort. This is illustrated in Fig. 4 for adaptive methods, the analysis of shells, and fatigue and damage.

Adaptive strategies [8–10] attempt to improve the reliability of computational models and as we can see from Fig. 4 the research activity in this field is growing. The same trend is for the analysis of fatigue and damage modelling [11–13]. The development in FE analysis of shells [14–16] is also illustrated in this figure. Even if there are difficulties associated with this analysis no visible effort in research activity can be registered.

2.3. Conference proceedings

Conferences permit informal exchange of ideas and information and make it possible to build up a network of personal contacts. Their main advantage is also that many papers report on research progress several months before publication in scientific journals. The main criticism of conferences is the uneven quality of papers and that the material presented is often a repetition of what is published elsewhere in the literature. Conference proceedings appear in the form of books, journals, CD ROM; they are a source of never-ending bibliographical confusions.

The first conference on FEMs was held at the Wright–Patterson Air Force Base, Dayton, OH in 1965 (Matrix Methods in Structural Mechanics). The first conference on BEMs was held at the Southampton University in 1978.

To be up-to-date with specialized conferences on FEMs and BEMs is relatively easy. The problems are conferences dealing with computational methods or other subjects of engineering where papers on FEMs or BEMs are represented. There are also numerous national and international conferences and symposia being held worldwide (some examples: Int. Conference on Computational Structures Technology, World Congress on Computational Mechanics, The Mathematics of Finite Elements and Applications, Int. Conference on Boundary Elements, BETECH, etc.), yielding annually hundreds of relevant papers. The last category are the users conferences. These include presentation of papers on applications of the specific software such as NASTRAN, ADINA, ABAQUS, ANSYS, LS-DYNA, etc.

The conference calendar can be found as a separate section in many journals, e.g. International Journal of Mechanical Sciences, Computers and Structures, Journal of Applied Mechanics (ASME), etc. or on the web: Internet Conference Calendar (conferences.calendar.com), International Conferences and Symposia in Mechanics (www.tam.uiuc.edu/events/conferences.html) and many others.

3. Finite element and boundary element software

First, in this section, some notes on the development of hardware in connection to the computational struc-

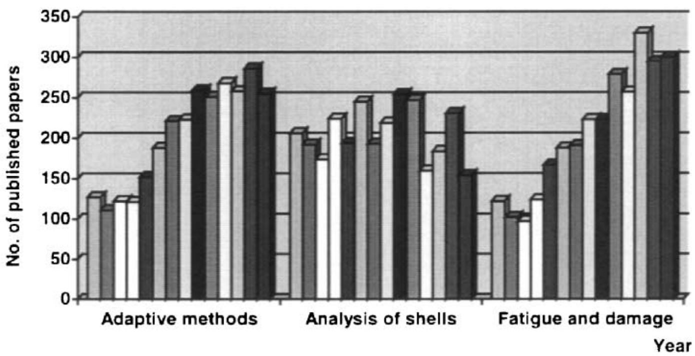

Fig. 4. Chronological distribution of FE papers on various topics (1986–1999).

tures technology will be given. Then, from a historical point-of-view, general purpose and special-purpose FEM and BEM programs will be considered.

FEM and BEM computations are currently used in a broad range of applications, not only in structural and solid mechanics but also in areas such as biomechanics, geomechanics, electromagnetics, thermal sciences, acoustics, coupled problems, multi-physics problems etc. Large structural calculations with complicated 3D geometry for complicated materials and loading history are today also possible. These achievements are due to the fact that the power and range of capabilities of computers are increasing all the time.

In retrospect, the period from the 1960s to 1990s in the hardware development can be divided into several phases. At the beginning there were mainframe computers, mostly UNIVAC1 and IBM704, 705. The next phase of hardware opened with IBM System 360; also UNIVAC continues with new models. Other manufacturers on the market are Burroughs, CDC and NCR. In the third period minicomputers appear. They are much more cheaper than mainframes but roughly comparable capacity. Minicomputers led to the development of distributed information systems. After 1978, PCs and later on superminicomputers are starting to appear. They brought the computer on the user's desk. During 1980s the main emphasis in hardware development is on supercomputers with pioneers such as Control Data, Cray Research, Amdahl, Hitachi, etc. The traditional supercomputers were equipped with a single processor. First commercial parallel computers containing microprocessors are available on the market in the mid-1980s. The late 1980s have seen relatively complex applications of supercomputers.

Future computational environment will apply highly parallel systems and metacomputers with speeds in the tera-flop range. Meta-computers can be defined as a virtual integrated computing environment with geographically separated resources connected by one or more high-speed interconnectors [17].

The age of PCs started in 1971 with the launching of two important products: the first commercially available microprocessor and the first floppy disc. The first produced PC was the MITS Altair 8800 in 1975. Microsoft and Apple were founded in 1976. In 1981 the first IBM PC was launched, based on Intel's 8088 and using MS-DOS. The first version of Windows was introduced in 1985 and came to dominate the PC operating environment. Then Intel brought out the 386, 486 and Pentium family of processors. The Internet entered in 1994 adding further dimension to PC use. It is estimated that this year it will be some 550 million PCs in use worldwide. At this end of computing spectrum we can wait development of handheld and wearable computers with cellular technology implemented to support portable computing and structural health monitoring.

Personal workstations are relatively large PCs. They are necessarily distributed with the person and interconnected to one another forming a single, shared (work and files) but distributed computing environment. The user communicates to a file server or central computer. Workstations have been introduced in 1981 by Apollo, SUN, Xerox, etc. Today they are very effective computational tools used in many engineering offices.

The FEM and BEM software has been developed for all computer platforms described above and their usage in engineering is increasing rapidly. A great impetus for their use at present is the drastic decrease of hardware costs. Also the capabilities of the FE and BE programs have continuously increased and have been more user-friendly to run. Some FEM codes have been integrated to large CAD systems. Fig. 5 chronologically illustrates a number of papers dealing with microcomputing (PC computing) [18], supercomputing (incl. parallel processing), and pre- and post-processing. The time period is 1980–1999. As can be seen, at present, almost no activity is directed to PC computing but the intense efforts have been devoted to the development of efficient computational strategies and numerical algorithms for new powerful high-performance computers. Here

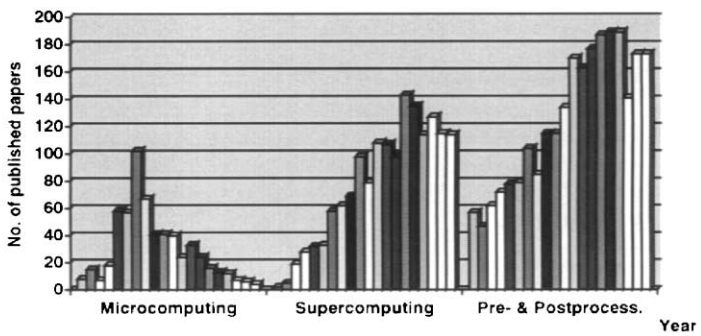

Fig. 5. Chronological distribution of FE papers on implementation topics (1980–1999).

the emphasis is on the vector and parallel processing [19].

The main reason for the developing and application of pre- and post-processing programs was to reduce the engineering time for input data preparation, processing of results, and to eliminate human errors during the data set creation for the analysis program and results interpretation. Today analysis processes are unthinkable without pre- and post-processing programs that are usually fully integrated with analysis programs. Extensive research has been devoted to automatic and semi-automatic mesh generation in 2D and 3D environments [20–22]. The cost and accuracy of the final numerical analysis depends first of all on the quality of the generated mesh. A significant effort has also been devoted to adaptive mesh generation, a mesh with varying density of elements. Mesh quality is too dependent on the user's practical experiences and the knowledge of the theory of finite elements. For mesh improvement, AI techniques have been added, e.g. to control mesh density, identify critical regions, give recommendations for the choice of element type, etc.

Modern visualization techniques implemented in post-processing operations can present, depending on the graphics display hardware which is available, wire-frame, hidden-lines or hidden surfaces, filled, light-source shaded, colored displays/plots of both models and results. In the visualization of the analysis we need an approach that enables easy control over the analysis process by interactive user input according to the visualized results from the numerical data.

The development of expert systems as an aid for non-experienced users of FE analysis started in the middle of 1980s [23]. From the available literature it can be concluded that the area of the expert system code development is not successful as was believed a couple of years ago. To the author's knowledge no commercial expert system for FEM is available and it is questionable if any will appear in the near future. At present there are some prototypes of expert systems in existence but their usage in general is not reported.

There have also been changes in programming paradigm, from the procedure oriented to the object oriented [24]. The last named programming technique usually leads to smaller programs, provides better data management and simplifies program extensions.

The software development and later applications require the integration of disciplines such as structural mechanics, material science, computer science, numerical and discretization techniques; it usually involves a sequence of five steps [2]: observation of the response phenomena of interest, development of computational models for the numerical simulation, development and assembly of software and hardware, post-processing and interpretation of the predictions of the computational models, and utilization of the computational models in the analysis and design.

4. General and special-purpose programs

The first FE software has been developed between 1960 and 1970 in the aircraft industry as in-house programs and mainly was based on the force method of analysis. Parallel efforts in universities and industry led to the development of general purpose programs, based on the displacement method (later on mixed and hybrid methods) such as those listed in Table 2. These programs have been released in the Europe and USA. Some of them have continuously been further developed and are used today. The FEM implementation started for linear static, then for linear dynamic problems, and continued to problems with material and/or geometric non-linearities.

FE and BE software could roughly be classified into two main categories—general purpose and special-purpose programs. General purpose programs are large programs or integrated systems that are oriented towards general use in different applications fields. Special-purpose programs are relatively small specific programs with enhanced features for certain analysis capabilities. Their use is limited to a specific application area.

According to the origin point of view there can be distinguished academic programs and commercial ones. Academic programs serve primarily as an education or research tool. They are often available for a nominal fee for other users for non-commercial applications. The documentation of these programs is often limited, and programs are not rigorously tested. Programs commercially available are tested and fully documented. The third category of programs are those developed at industrial companies. They are usually not for outside users. Most of programs have been developed in an academic environment.

In the author's database there is information about 1538 FE codes and 145 BE codes. It can be therefore concluded that not many BE codes are in existence, especially not the commercial BE codes. Anyway, some of them are listed in Table 3.

The last figure (Fig. 6) illustrates the total number of general purpose and special-purpose FE and BE programs which have been developed for various topics/application fields. These programs have also been retrieved from the author's database. Again, it has be pointed out that many of FE and BE programs in existence are missing in the database (especially the academic ones).

From this figure it can be seen that most FE programs have been developed for specific applications, namely for the analysis of dynamic and non-linear

Table 2
Historical listing of some general purpose FE programs

Year	Program name	Developer	URL address
1965	ASKA (PERMAS)	IKOSSGmbH,(INTES),Germany	www.intes.de
	STRUDL	MCAUTO, USA	www.gtstrudl.gatech.edu
1966	NASTRAN	MacNeal-Schwendler Corp., USA	www.macsch.com
1967	BERSAFE	CEGB, UK (restructured in 1990)	
	SAMCEF	Univer. of Liege, Belgium	www.samcef.com
1969	ASAS	Atkins Res. & Devel., UK	www.wsasoft.com
	MARC	MARC Anal. Corp., USA	www.marc.com
	PAFEC	PAFEC Ltd, UK now SER Systems	
	SESAM	DNV, Norway	www.dnv.no
1970	ANSYS	Swanson Anal. Syst., USA	www.ansys.com
	SAP	NISEE, Univ. of California, Berkeley, USA	nisee.berkeley.edu
1971	STARDYNE	Mech. Res. Inc., USA	www.reiusa.com
1972	TITUS (SYSTUS)	CITRA, France; ESI Group	www.systus.com
	DIANA	TNO, The Netherlands	www.diana.nl
	WECAN	Westinghouse R&D, USA	
1973	GIFTS	CASA/GIFTS Inc., USA	
1975	ADINA	ADINA R&D, Inc., USA	www.adina.com
	CASTEM	CEA, France	www.castem.org:8001/HomePage.html
	FEAP	NISEE, Univ. of California, Berkeley, USA	nisee.berkeley.edu
1976	NISA	Eng. Mech. Res. Corp., USA	www.emrc.com
1978	DYNA2D, DYNA3D	Livermore Softw. Tech. Corp., USA	www.lstc.com
1979	ABAQUS	Hibbit, Karlsson & Sorensen, Inc., USA	www.abaqus.com
1980	LUSAS	FEA Ltd., UK	www.lusas.com
1982	COSMOS/M	Struct. Res. & Anal. Corp., USA	www.cosmosm.com
1984	ALGOR	Algor Inc., SA	www.algor.com

Note: some of listed programs have several versions but only one URL address is presented. Readers interested in other FE programs (public domain programs included) are referred to, for example: www.engr.usask.ca/~macphed/finite/fe_resources/fe_resources.html; nisee.berkeley.edu; femur.wpi.edu; or [25].

Table 3
Historical listing of some general purpose BE programs

Year	Program name	Developer	URL address
1978	SURFES	Kawasaki Heavy Ind., Japan	www.crc.co.jp/CRC/eg/Surfes/Surfes.htm
1980	CA.ST.OR 3D	CETIM, France	www.spbo.unibo.it/ateca/cetim.htm
1981	BEASY	Computational Mechanics, UK	www.beasy.com
1982	BETSY	T-Programm GmbH, Germany	
1983	GPBEST	BE Software Tech. Corp., USA	www.gpbest.com

Note: Readers interested in other BE programs are referred to the Boundary Element Resources Network (BENET) www.olemiss.edu/sciencenet/benet or to [6].

problems. The area of fracture mechanics is promising for the development of special-purpose BE codes.

5. Conclusions

It is not the author's intention to draw any conclusions. To give a view of the future of FEM or BEM is an extremely difficult task, therefore this presentation should be considered as an example of a different usage of a database dealing with numerical methods.

Introduction to references

Ref. [1] describes the database, MAKEBASE, which served as the base for all bibliometric studies presented

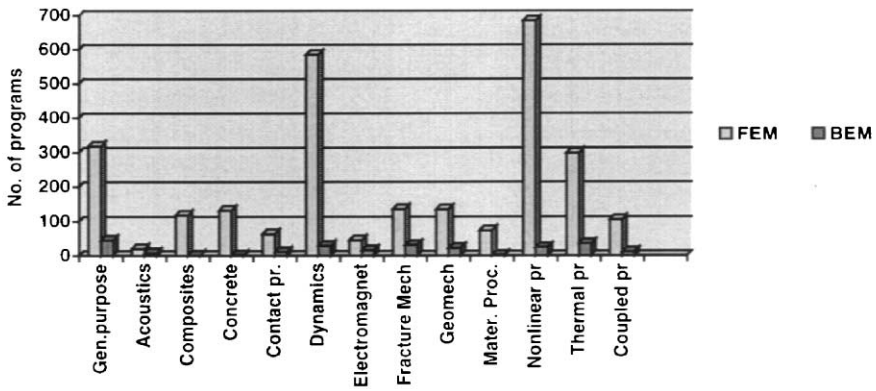

Fig. 6. FE and BE codes for various topics.

in this paper: chronological distribution of FE and BE papers, FE and BE papers for various topics and materials; FE and BE codes developed for various topics are also taken from this database or Ref. [25] can be consulted. The first bibliography on FEs ending with references for the year 1975 has been compiled by Norrie and De Vries [7]. This collection is important from the historical point of view only. The history and modern insight into FE technology is reviewed by Noor in [2] and [17]. For parallel implementation of FEM see book written by Topping and Khan [19].

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