Enterprise Science for Technology-intensive Company and its Elaboration by Systems Thinking

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Abstract

The aims of this paper are two-fold; the first is to discuss a new discipline, the enterprise science advocated by one of the authors of this paper (Tschirky, 2000), especially for understanding and managing technology-intensive companies. The second is to point out some contributions of systems thinking to promoting the enterprise science to evolve into a more integrated as well as feasible form.

After claiming that technology gap is not sufficiently referred to in the understanding of management theories based on an intensive survey, we first argue the enterprise science, which one of the authors proposed as an comprehensive basic science for dealing with both technology and management. Then, we point out possible contributions of systems thinking to elaborating the enterprise science to an integrated form. We also give a glance to actual implementations of the science at ETH, Zurich, Switzerland.

Key Words: Enterprise science, Technology-intensity company, Technology management, Systems thinking, Technology gap

1. Introduction

The aims of this paper are two-fold; the first is to discuss a new discipline, the enterprise science advocated by one of the authors of this paper (Tschirky, 2000), especially for understanding and managing technology-intensive companies, and, the second is to point out some contributions of systems thinking to promoting the enterprise science to evolve into a more integrated as well as feasible form.

Matsushita, one of the largest Japanese electronics manufacturers, similarly announced on 9 September the closure of its 4-megabyte chip production plant in Pyallup, Washington, US, planned for December. Similar restructuring measures had been announced the previous week by Fujitsu and Hitachi (FT, 10.9.98). – What management instruments might have lowered the risks of such investments? What other possibilities might have been explored by these firms, in view of their responsibility for the social effects of employee dismissal?

Early in 1997 Deloitte Touche Tohmatsu International conducted a study among the 1,000 leading companies in Germany, France, Great Britain and the Netherlands. The study focused on which decision-making factors were considered by the top management of these to be the most important to activate as we enter the next century. The effects of technological change were accorded the greatest significance; in second place came the introduction of a single currency neck and neck with the recruiting of qualified staff (Deloitte Touch Tohmatsu International/Opinion Research Business 1997). - What are the specialist and personnel prerequisites for making far-reaching, first-hand technology decisions at the highest management levels (board of directors, company management)? Can this type of technology decision be delegated at all?
The questions posed above reflect typical challenges which are increasingly becoming facets of company reality. We observe, however, that no sufficient substantial impetus towards the practical solution of company problems is found in almost any of the approaches and theories. Indeed, as will be argued in Section 3, most of all the approaches in general management theories in common take the formal points of view (expressed with varying degrees of explicitness). Most of all involve basic frameworks for the company and its management, which include a large number of company functions, every conceivable relationship structure, and interaction with the relevant environment. The material design of such formal frameworks is, however, in no way comprehensive. In the material design economic and social science knowledge have been deepening; but the natural and engineering sciences, which are the backbone of competence especially for technology-intensive companies, are hardly included. The enterprise science was developed and proposed by a noticeable gap between the received picture of company reality by general management theories and what actually goes on there.

Over the last few years there has indeed been a significant growth in the popularity of, e.g., literature on technology management (see Figure 1). This development can not, however, close the “technology gap” in the understanding of general management.

The existence of this gap has caused serious management problems. It, firstly, generated such attitude in upper-echelon of management that technology is a job for subordinates. The existence also led to the (directly linked) minimal attention accorded to both the opportunities and the perils of technology deployment, despite the risk that these may be embedded in initial upper management and administrative decisions. Secondly, it is uncertain whether, or how, isolated and aspect-wise management statements may feasibly apply to the process of management decision-making.

In spite of the technology gap, technology-intensive companies in reality anyway have to deal not only with economic and social science knowledge, but also with the natural, engineering, work and environmental sciences concerning their activities and (in particular) their management. Firms are forced into a situation where they must take into account a large body of disconnected scientific knowledge and somehow integrate it before it may be deployed.
Because of the demanding specialist nature of this task it is not surprising that, as an alternative to their internal solution, outside consultants are often called in to solve company problems. But, of course, the top management cannot escape from the technological matters, since it is those who take the ultimate responsibility for the final decisions, however technical they are.

The gap may also be explained by looking at the university context, where theories are generated. The “delegated” nature of the integration task in universities reflects what is commonly criticized in those institutions: they traditionally produce highly specialized disciplinary knowledge and teach or publish it mainly in an “atomized” form. The fact that firms themselves then have to carry out the integration task is one of the results of this general academic trend. The other (no less problematic) is that students of current management theory – including the managers of the future – are educated to a picture of the enterprise upon which management decisions may not reliably be based.

In light of the above, it is absolutely crucial not only that the foundations of company and company management understanding be rounded out to cover current relevant scientific areas but also that they be applied at the level of basic science – in completed form – to the actual key tasks of the company. The relevant scientific areas include, in addition to the technology-oriented sciences, those involving cultural, social, economic and ecological company issues. Without establishment of fully complete foundations it seems unrealistic to develop concepts of the enterprise and its management which really apply to present and future company reality.

In this paper as such a fully complete foundation we first will discuss the enterprise science. Then, we will show that systems thinking is helpful for the enterprise science to evolve into not an atomized but integrated form.

2. Closing the technology gap in three steps

In broad lines the evolution of technology management can be viewed in three steps (Refer to Fig. 2).

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Fig. 2  Evolution of Technology Management
A first major step to establish technology management was taken in the middle of the eighties. A Task Force on Management of Technology was appointed to distil and expand the results of a workshop conducted in May 1986 under the aegis of the Cross-Disciplinary Engineering Research Committee and the Manufacturing Studies Board. As a result the report “Management of Technology: The Hidden Competitive Advantage” was edited and approved by the National Research Council (NCR 1987). The workshop was held in the light of the relative decline in the international competitiveness of U.S. industries then which became a major issue of national debate (NCR, 1987: xvii).

The discussion revealed that although Management of Technology (MOT) had existed as a limited field for at least 25 years, it had not attained the status of a recognized discipline. In this NCR report MOT is defined by: ‘Management of technology links engineering, science, and management disciplines to plan, develop, and implement technological capabilities to shape and accomplish the strategic and operational objectives of an organization.’

Key elements of MOT in industrial practice are (1) the identification and evaluation of technological options; (2) management of R&D itself, including determining project feasibility; (3) integration of technology into company’s overall operations; (4) implementation of new technologies in a project and/or process; and (5) obsolescence and replacement (NCR 1987).

A second step taken in the evolution of technology management was characterized by a paradigm shift. Rather than considering technology management as the “missing link” between engineering & science and management, the vision “Bringing Technology into Management” was developed (Tschirky, 1991, 1996, 1998). Its basis is the postulate that “technological issues” will no longer be solely of concern in the context of directly technology-related managerial functions such as R&D and production management but will be of prime concern for general management at all levels. Realizing this vision the concept “Integrated Technology Management” was developed. It represents technology management using a concept of general management.

To this end three levels of (technology) management are distinguished: Firstly, at the normative level, primary decisions must be made according to the long-term goals of the company. This requires the development of a consistent company policy. The normative level is thus oriented towards the principle of perceived meaning. At this level it is not only the making of long-term decisions which is vital for the company’s future; but also essential is who makes these decisions. This question refers to the upper decision-making levels of the company, i.e., the top decision-making bodies of technology-intensive companies (board and top management) must contain a balanced representation of technical and non-technical abilities. Establishing the CTO (Chief Technology Officer) function may be a first solution to this request.

At the strategic level it is essential that company policy be transposed into comprehensible strategies. Here the principle of "doing the right thing", and thus the principle of effectiveness, dominates. Strategies lay middle-term emphasis on the selection of those technologies necessary for the production of present and future products. In particular, decisions are made as to whether these technologies will be developed in-house or in conjunction with other firms, or whether they will be purchased completely from other organizations.

Relevant trends in strategic technology management indicate that strategic alliances, process management and innovation-boosting structures are taking on increasing significance, as is "Technology Scanning and Monitoring", i.e., the comprehensive accumulation of information concerning existing and developing technologies. A further focus involves concepts of socio-technical systems design. Decisions concerning technology are, however, only one of
many sets of decisions of similar significance, such as market decisions or those concerning procurement of capital. These decisions are also, as a rule, of a strategic nature and thereby oriented towards strengthening the competitive ability of the company. Technology, market, and capital-procurement decisions are interdependent: the opening of new markets requires financial means and may also depend on the mastery of new technologies - and vice-versa.

Finally, at the operational level of management responsibility is taken for transforming strategies into practice in the context of short-term goals. Operational management expresses, for example, in concrete R&D projects in which the necessary personnel, financial and instrumental resources are deployed according to a plan. Here the pointer is "doing things right", implying accordingly the principle of efficiency.

In summary, according to this view technology management can be conceived of as an integrating function of general management which is directed towards the normative, strategic and operational management of the technology and innovation potential of an organization.

The enterprise science this paper argues is positioned as the third and final step to close the perilous gap between management theory and technology reality of companies. It includes developing a fundamentally new concept of managing technology-driven or -intensive companies. Before we will outline possible contours of it in Section 4, however, we need to briefly summarize foundations of current understanding of companies and their management.

3. **Current understanding of companies and their management (Tschirky, 2000)**

Since today’s understanding of enterprises and their management is founded on a large number and various kinds of theories and empirical approaches, it is rather difficult to summarize it systematically. Indeed, some are focusing on relevant functional aspects of organizational activities and themes, such as work processes, human resources deployment, decision-making processes, strategic management, international management, technology and innovation management, production, operations research, turnover, marketing or financial management.

Others are attempting to comprehend the enterprise as a holistic entity, and which provide general recommendations for the shaping of company management from this standpoint. It is this latter group that is central to the examination below; namely, the fundaments of Business Economics, Industrial Science, Management Science, and the Theory of the Firm will be examined. To evaluate these theories the following two core questions are used:

1. To what extent are these approaches suitable – in the sense of a self-contained enterprise science – for the realistic representation of a company’s present and future sensitivity to technology?

2. Do these approaches provide the prerequisites for a company management training which corresponds to present and future requirements

3. **1 Business Economics**

Business Economics (BE) dates back to the founding of the commercial universities of Leipzig, Aachen, Vienna, and St. Gall in 1898/99. The first important BE publications from this period bear titles such as “System of World Trade Theory”, “General Theory of Commerce”, “Private Industry Management as an Art”, and “General Business Economics as Private Industry Management of Trade and Industry”. According to Wöhe (1996), up to the mid-20th century three perceptions of BE grew, developed to continue to be influential to varying degrees today: empirical-realistic BE; normative-evaluative BE; and the theoretical branch of BE.
In his recent book *Eisenführ* (1998) establishes as the research focus of BE: “... the economically-relevant processes in businesses and between businesses and their environment”. The concept “business” is synonymous with “enterprise”, while the latter is understood as an economic unit of which businesses exist as technical-organizational sub-units. The BE concept used to describe this is depicted in Fig. 3.

![Figure 3](image-url) Companies and their environment

According to *Eisenführ*, the scientific goal of BE is to create descriptive and prescriptive outlines. To this end *real phenomena* are described and explained, while, via prescription, aids to practical decisions are elaborated (1998). This formal business economics framework is structured under the main headings of planning, decision-making and controlling; employee management; organization; company constitution and company relationships; finance; personnel; accounting; turnover; and production. It is apparent here, too, that the sensitivity of enterprises to technological change is taken into account neither in the description of a firm’s environment nor from a company-internal perspective. Furthermore, according to the publication’s structure (*Eisenführ*, 1998) the issue of “innovation” is finally dealt with under the “ad hoc” section with the remark that this special form, when it arises in the organization, spawns issues which “... require innovative solutions which can be reached only through the cooperation of specialists of different disciplines”. Another gap in *Eisenführ*’s approach is that he refers to no specialized knowledge concerning modern work forms which is available today via the work sciences.

In the light of such approaches, Business Economics presents itself as a method for representing aspects of the enterprise mainly from the economic perspective. At the same time, because of its technology gaps, description and analysis via BE appears insufficient for
comprehending the peculiarity of technology-intensive enterprises and their management with adequate closeness to reality.

3.2 Industrial Science

Industrial Science had its beginnings in the Scientific Management work of Taylor (1911). The fundamental aim of Scientific Management is for the company to attain the “highest possible level of prosperity”, with the lowest possible expenditure on human labor, raw materials and capital, machinery and building. This would be “the result of the most economic application of the worker and the machine, i.e. the worker and the machine must achieve their highest productivity, their greatest efficiency”.

A second source for Industrial Science was the work of Fayol (1916), who also aimed to apply scientific procedure to company management. In contrast to Taylor, however, Fayol concerned himself primarily with the firm’s management and organizational activities. It is well-known that the two major themes of IS as work structure and company-organisational design.

It can be said that the delimitation and orientation of Industrial Science have been successively extended since the 1950s. The pervading characteristics of Industrial Science are; firstly, its view of companies as socio-technical productive systems, which are closely networked with other enterprises as well as with their technological, social, economic and ecological environment. Secondly, because of its scientific and engineering base, Industrial Science puts emphasis on comprehending development, production and logistics processes from the ground up, and its ability to realize innovative optimization and design concepts.

When evaluated according to the two core questions, it is seen that Industrial Science with its present technological-work sciences focus does comprehend real company experience to a great extent – but not completely. Since there are significant gaps in its understanding of company management, both questions must be answered rather in the negative.

3.3. Management Science

Management Science has grown up primarily around US and British publications concerning the task of general management. Among those come, firstly, the works of Drucker (e.g. 1998a, 1998b), which present the numerous facts of company management in comprehensive depth. His chosen level of investigation has placed Drucker’s work, as a basic complement to methodology-oriented textbooks on companies and their management, in an undisputed position at the forefront. More concrete statements concerning general management tasks are found in Kotter (1982), but here central aspects, such as those of technological change and its socio-technical implications for every type of enterprise, are not addressed. Similar gaps are found in Mintzberg (1989), a work which presents the management task with vivid illustrations of cases from practice.

In management science the actual technology sensitivity of companies is granted only a marginal position. The theme of “technology” is reduced to aspects of information technology, and the treatment of R&D is limited to confirming the growing consciousness that R&D tasks should be actively included as part of company events.

In the context of Management Science the answer to both core questions is “negative”. A great amount of knowledge concerning the special nature of companies and their management is indeed found there, but the “technology gaps” are still too wide.

3.4. Theory of the Firm

The Theory of the Firm concept grew out of publications which consider the enterprise from a micro- and macroeconomic perspective. In his approach “The Theory of the Firm” (1937),
Coase posits the question as to why companies emerge in a market economy. His conclusion is that certain economic activities are more economically realizable in the marketplace within the context of a company than outside it. In other words, the reason for the founding of enterprises is that transactions via the market, (i.e., the use of the market for economic processes), are not cost-free, but generate transaction costs for the firm (Williamson 1975, 1985); and when these transaction costs exceed organizational costs, companies emerge.

While Coase attempted to explain the emergence and existence of enterprises, more recent approaches to transaction cost economics (Williamson 1975, 1985) went further, trying with the help of the transaction cost approach to determine the most efficient form of coordination for the fulfillment of specific tasks. This concept is implemented, for example, to establish whether production or development should take place inside or outside of the company (Pisano, 1990). For it is true that in order to find the most efficient form of coordination, transaction costs must be taken into account as well as pure manufacturing costs.

As this approach (in spite of its extension to include information and knowledge) is purely economic, our two core questions do not apply.

4. The Enterprise Science: A new basis for managing the technology-intensive company

The Enterprise Science concept is oriented towards establishment of fully complete foundations for the understanding of companies and their management. Its basis elements are illustrated in figs. 4 and 5.

Fig. 4, on one hand, takes into account the fact that descriptions of current company reality are based upon knowledge from many scientific disciplines (e.g. macro- and microeconomics and the social, legal, environmental, natural, engineering and work sciences). It, on the other hand, symbolically indicates the scientific foundations upon which current management training approaches rest.

As already illustrated in the previous section, determinants in company management today are certain characteristic modes of thought which developed via various factors in the history of
management. Business Economics primarily claims the economic principles, in the light of which enterprise activities and management are interpreted. Current Industrial Science emphasizes the technological aspects of development and the generation of market performance, and socio-technical work structures. Management Science comprises a many-level integrative approach which depicts the multitude of company functions in all its internal and external complexity. It still leaves, however, various gaps in the material structuring of its relationship network, especially in the context of current technology reality. The Theory of the Firm is dominated by macro- and micro-economic theories, which do not take into account socio-technical events in the company.

The concept of Enterprise Science is founded on the assumption that in research it is possible to draw on all the relevant empirical and science-based areas of scientific knowledge required to describe the enterprise (see Fig. 5).

![Figure 5: Enterprise Science: areas of cognition](image)

In Fig. 5 the object area circumscribes the whole enterprise and determines the formal framework of Enterprise Science. Its structure is the result of primary integrative work, and consists of bringing the knowledge of the basic sciences and of previous management theory into thematic form as a coherent basis for Enterprise Science. This should provide a foundation that is not only suitable for explaining company reality, but also for researching and finding solutions to company problems. In contrast stands the problem area of Enterprise Science. This covers all of the non-trivial problems of management and its activities, and their solutions. To this area belongs, for example (besides what is mentioned in), on the management level the creation and operation of so-called “technology intelligence” systems (sometimes as a part of “business intelligence” systems) to ensure the up-to-date supply of relevant technology information.

5. Elaboration of Enterprise Science

5.1 Contributions of Systems Thinking to Enterprise Science

The realization of the Enterprise Science concept is without doubt a demanding undertaking. The main challenges will be the elaboration of a many-disciplinary and coherent management knowledge basis, the development of effective methods of knowledge integration, and accomplishment of the integration task itself together with the ensuring of its relation to company practice. Indeed, the enterprise science may typically bring together experts from economics, the social sciences, law, the work sciences, engineering and the natural sciences,
management science, and management practice specialists. This interdisciplinary engagement in a common research goal facilitates the integration of existing disciplinary knowledge right from the start.

Furthermore, procedures of interdisciplinary cooperation must be practiced which make possible the combining of initially non-comparable bodies of knowledge from individual specialist areas. It must, for example, be possible to limit the parameters surrounding a particular company-specific issue while still involving a range of technological, work science, economic, legal, ecological and social options in finding solutions. The common denominator of the diverse bodies of knowledge might be the influence of all, however variously expressed, on the viability of enterprises in the context of social and technological change.

It is our claim that in order to integrate and elaborate disciplines constituting the enterprise science, systems thinking is helpful and useful. A systems thinking of the observed world and to its problems are, in general, applicable to any different disciplines (Checkland, 2000). All these efforts constitute so-called the systems movement. It is the set of attempts in all areas of study to explore the consequences of holistic thinking. The program of the systems movement might be described as the testing of the conjecture that holistic ideas will enable us to tackle the problem which the method of science finds so difficult.

It might have happened that the exploration of holistic thinking developed in various disciplines using the language appropriate to each different subject. What in fact has happened is that wholes in many different areas of study, from physical geography to sociology, have been studied using the ideas and the language appropriate to systems of any kind.

The systems movement, at least a loose federation of similar concerns linked by the concept ‘system’, owes to Ludwig von Bertalanffy very much. It was von Bertalanffy who insisted that the emerging ideas in the various fields could be generalized in systems thinking.

In 1954 von Bertalanffy, a biologist, together with an economist (K. E. Boulding), a physiologist (R. W. Gerard), and a mathematician (A Rapoport) launched the Society for General Systems Research (presently, International Society for Systems Sciences). The purpose was to encourage the development of ‘theoretical systems that are applicable to more than one of the traditional departments of knowledge’. It is clearly described by the well-known statements:

1. To investigate the isomorphy of concepts, laws, and models in various fields, and to help in useful transfers from one field to another;
2. To encourage the development of adequate theoretical models in areas which lack them;
3. To eliminate the duplication of theoretical efforts in different fields;
4. To promote the unity of science through improving the communication between specialists.

As we can see easily from these statements, systems movement tries to provide general ‘meta-science’ by nature, namely general systems theory. Systems thinking starts with an observer/describer of the world outside ourselves who for some reason of his own wishes to describe it ‘holistically’, that is, to say in terms of whole entities linked in hierarchies with other wholes. This leads to the most basic prescription of what the observer's description will contain: his purpose, the system(s) selected, and various system properties such as boundaries, inputs and outputs, components, structure, emergence and hierarchy, communication and control, the means by which the system retains its integrity, and the coherency principle which makes it defensible to describe the system as a system.

It is our claim that we identify the enterprise science, which consists of a large number of disciplines that relate with each others, as an artificial system and elaborate it by applying systems thinking to it.

There are quite a many contributions from systems thinking to the enterprise science. Some of them are:

1) Systems thinking should be useful for promoting the unity of the enterprise science through
improving the communication between disciplines involved and committed to it. It is certainly true that similar but different terminologies are employed in each discipline. Systems concepts should play a role of interpreter among the disciplines. Moreover, systems thinking may not only eliminate the duplication of theoretical efforts in different fields, but also encourage the development of adequate theoretical models original for the enterprise science. It should be also fruitful to investigate the isomorphy of concepts, laws, and models in various fields constituting the enterprise science.

2) Systems thinking should be helpful to make the enterprise science more feasible in practice by structuralizing it. The enterprise science consists of such a large number of disciplines that we need to assign priorities to each area when we try to use and educate it in practice, since the users, whether they are practitioners or researchers, are not ‘omnipotent’. It is rather impossible for them to familiarize themselves with every field of the science. Since systems thinking is primarily concerned with structure or interrelationship of an integrated whole, it certainly contributes to identify, for example, hierarchy in the disciplines. In this process, we can also shape up the enterprise science by dropping redundant and/or duplicated concepts to produce a more condensed framework.

3) Systems thinking should contribute the enterprise science to establishing identity. As an ultimate stage of the enterprise science every component should get fused to become an integrated discipline, not simply a mixture of a lot of disciplines. Systems thinking should be helpful to this end, since it is concerned with clarifying and promoting emergence properties of the enterprise science as a system.

5. 2 Learning from practice

Though the proposed enterprise science is useful but tentative, it is true that management at technology-intensive companies cannot wait for the completion of it. It is also clear that science like the enterprise science can evolve by learning from the practical implications. One of the authors of this paper has started to implement it at the ETH Zurich in the Department and Division of “Industrial and Production Sciences”. The carrying out of these lecture and research projects will put the ETH Department in a position to accumulate, in addition to specialist-area knowledge, integration knowledge focused on practice; and via their students to convey it either directly or indirectly to companies.

Four examples of this are as follows. The first involves the presentation of a knowledge-integrative lecture series. During the Summer Semester of 1998 a lecture entitled “The Market Launch of Technological Innovations” was offered in the context of the “Technology and Innovation Management” course. Students were assigned the task of evaluating a technology generated within the Department in relation to potential business opportunities. Made available to them were one technology each from the institutes of forming technology, textile machinery, and textile industry. A prerequisite for the students’ task work was their studies in previous semesters of the multi-faceted, disciplinary knowledge of the industrial and production sciences. Additional methodological knowledge was provided by representatives of the industrial sciences, and specific technological knowledge by members of each institute. A notable element of the lectures was the discussions which took place in the auditorium among the representatives of specialist disciplines with the goal of investigating the best possible use of the technology in question. The lectures were also given in the Winter Semester of 1998/99, this time with the addition of the Chair of Law and information concerning patents. The aim in future is to involve further specialist areas.

The second example is the training program “Leading the Technology Enterprise”. This involves a course that prepares selected executives from industry and the service sector for future tasks in upper-echelon management of technology-intensive enterprises. The program is offered jointly by the ETHs of Zurich and Lausanne and the International Institute for
Management Development (IMD), and because of its specialized, balanced structure already largely corresponds to the Enterprise Management concept as presented above.

The third example is a lecture series called “Discovering Management” which was offered successfully for the first time during the Winter Semester of 1900/2000. It is addressed exclusively to students with a purely technological background and therefore with no previous education in management-related subjects. The goal of the series is to motivate the students in entrepreneurial thinking and thus to complement their curriculum meaningfully with respect to their future careers.

The fourth example is the new ‘poly project’ currently under discussion. The plan is to select a research theme that is not subject-related but oriented towards a problematic company issue. At the fore is the management task of the Zurich Cantonal Hospital, which is confronted with the entire spectrum of the challenges presented by social, economic and technological change. The University of Zurich will also take part in the project. Typical research issues will surround the structure and content of enterprise vision, business strategy, legal structure, setup and process structure, and management instruments.

6. Conclusions

In this paper we discussed a new discipline, namely, the enterprise science, advocated especially for understanding and managing technology-intensive companies. After showing that technology gap is not sufficiently refereed to in the understanding of management theories so far by conducting an intensive survey, we argue characteristics of the enterprise science. Then, possible contributions of systems thinking to elaborating the enterprise science to a more integrated form. We finally refered to actual implementations of the science at ETH, Zurich, Switzerland to claim the validity of the science.

Bibliography


