Strategic Planning for Building Research—A Process Oriented Methodology

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Abstract: This paper explains and discusses the development of a strategic plan for the management of research in building in a planning horizon of 8–10 years. The plan has three major elements: (1) a knowledge base with ranked long range research needs in each discipline; (2) a second base which defines the main objectives of the building sector and the major interdisciplinary problems that must be solved in order to attain them; and (3) the procedures to be followed in order to initiate and carry out an annual research program in view of the strategic plan and the current information maintained in the two bases. This paper dwells first on the special features of research as a knowledge building and problem solving tool, and then describes the process of the actual development of the strategic plan for building research in Israel, including the construction of the knowledge bases and the generation of the annual research programs. Special attention is given to the objectivity and accountability of the process.

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Preface

Research and development is the main driving force toward the technology advancement of modern industry. In most industries, it is typically carried out inhouse, usually in large companies. Its expenses are considered as an investment in capital assets to be used for the enhancement of the company's production capacity. The situation is different in the building sector. The fragmentation of construction resources, the diversity of projects, and the long fruition period of any technological development result in research being more expensive and less beneficial for a building company than in other industries. Therefore, very seldom is building research carried out in private companies. It is usually sponsored and financed by public authorities, and carried out mostly in universities and public research institutes, while the majority of its end users are the private sector practitioners.

Because of the institutional separation of the research work from practice, there is often a considerable difference between the expectations of the sponsor, the end users, and those of the researchers. The end user, and in most cases the sponsor as well, is looking for the bottom line which will present him with a practical solution to his current problem, while the researcher is interested in a wider perspective and an understanding of the basic problem. The public sponsor also recognizes, to some extent, the significance of creating knowledge that may be beneficial in solving foreseeable future problems and not only those which exist at the present. Very often a single research study is only one stone in a wider mosaic, which elucidates the knowledge of a certain area, and it does not offer, of course, a solution to all the problems in that area, despite the fact that the end user or sponsor may expect it. As a result, a large number of research reports—even those which have been considered as a breakthrough in international professional literature—find their way to remote shelves and gradually "gather dust." Consequently, it has been recognized by all interested parties that there is a need to reduce, as much as possible, the gaps in understanding the nature of research and its benefits on the one hand, and its limitations on the other. An effective way to achieve it is by means of a strategic research plan that identifies the research subjects, which can either contribute directly to the immediate practice needs or to the basic knowledge to be used in the future.

In this paper, we review the process of preparing a strategic research plan for the Israeli Ministry of Construction and Housing carried out at the National Building Research Institute (NBRI). The plan was intended to fulfill the research needs of the building sector and create a framework for annual funding allocations for research proposals submitted to the Ministry. The study consisted of two parts, the first, which was of general nature, dealt with the methodology that then guided the whole plan preparation, and the second dealt with each professional discipline separately. The plan was prepared by a team of senior researchers; Professor Abraham Warszawski, as the team leader, and Professor Rachel Becker, Professor Sam Frydman, Professor Joshua Frostig, Professor Amnon Katz, and Professor Ronie Navon, as the experts in the areas of buildings performance, geotechnology, structural engineering, building materials and technology, and construction management, respectively (Warszawski et al. 2005). The study is reviewed in the following order: First, the concept of research and its main characteristics is explained, and its application to the area of buildings is reviewed. Next, the process of identifying the research needs and their preferences is examined in its strategic context by means of the systems approach. Finally, the procedures

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for the generation of the annual research programs and for their orderly implementation will be presented.

The full study included the development of the methodology and the implementation of a strategic plan for building research in Israel. This paper focuses on the strategic planning process rather than on context, and can be applied to other research fields as well.

Objective of the Study

The objective of the research study was to devise, for the public sponsor, a strategy for activating annual research programs in the domain of building construction with consideration of the actual needs of the building sector. The activation of a program includes the identification of worthy research subjects, determination of their priorities, and the selection of the preferred research projects to be included in every consecutive annual research program.

Research in the context discussed here may be viewed as a means for the creation of innovations and improvements in existing solutions, as well as a scientifically based engineering tool to be employed for the solution of problems that due to their complexity cannot be solved by the available "rules of good practice," which can be found in codes, standards, highly regarded professional publications, etc. It can also be used for the enhancement of available solutions to existing problems, when justified by their size or importance.

The general objective of this research study, as defined earlier in this section, can be translated into three distinctive tasks:

1. Devise a methodological framework for a strategic research plan in building.
2. Use this framework for developing an actual strategic plan to be implemented by the Ministry of Construction and Housing in a relevant planning horizon. The relevant planning horizon is the period of time for which the present planning premises can be applied without a need for significant revisions. It will mainly depend on the extent of the technological change in the subject areas and the intensity of the research pertinent to them. In the special context of the Israeli building sector, it has been determined by common consent to be 8–10 years.
3. Devise procedures for using the strategic plan as a basis for the preparation of annual research programs in the planning horizon.

Solution Model

The problem of the strategic planning examined here can be defined in the system analysis terminology as follows.

Every year of a given planning horizon, a sum of money is allocated by the public sponsor for a set of most promising projects selected from a large inventory of research project alternatives. Each project, if selected for execution, has a given cost and a given benefit associated with it. The project may be planned for a one year's execution or more. In the latter case, a decision must be taken in the next year's program as to whether to continue it.

A decision with regard to each project may be seen as a decision variable of the system. The value of the decision variables would generally be Boolean, Yes or No, determining if the project is to be included in the winning set. The decision variables can also be multidimensional (Warszawski 1973) if the project can be executed in several mutually exclusive modes.

Each project has as its parameters the cost of its execution and the prospective benefit of the implementation. Other parameters of the project pertinent to the selection, such as the stance of the researcher, an immediate/urgent need for the findings, or a very convincing implementation, may be included in the model as well.

The choice of the projects to be included in the annual winning set is constrained by the total budget allocated for the year, by the amount of resources in different disciplines, and by the possible technological dependencies between the projects. The optimal set, the object of planning, should be the one which renders the maximum benefit to the society served by the building sector subject to the system constraints.

The mathematical representation of the system, its model, can be defined as follows:

Let

$i=1,2,\ldots,I$—a set of possible research projects in the planning horizon;

$t=1,2,\ldots,T$—a set of annual research periods in the planning horizon T; and

X_{it}—a bivalent variable: $X_{it}=1$ if the project is to be carried out in the period T, and otherwise, $X_{it}=0$.

The parameters of the system are:

C_{it}: Present value of the budget of research i in period t;

G_{it}: Net present value of the explicit direct research benefits over the innovation's total economic life that can be assigned to the research work carried out in period t in project i; and

V_{it}: Net present value of all intangible benefits, which may influence the attractiveness or implementability of the project.

The objective function of the system may be, therefore, defined as follows:

$$\max\left\{\sum_{t}^{T}\sum_{i}^{I}[X_{it}\times(G_{it}+V_{it}-C_{it})]\right\} \quad t=1,2,\ldots,T, \quad i=1,2,\ldots,I \tag{1}$$

Subject to these constraints

$$\sum_{i}^{I}[X_{it}\times C_{it}]=U_t \quad t=1,2,\ldots,T \tag{2}$$

which defines the budget, U_t, allocated to research by the sponsor each year in the planning horizon and

$$F_j(X)<0 \quad j=1,2,\ldots,J \tag{3}$$

With each function F_j defining another constraint on the set of variables X, The constraints may be external: Imposed by the codes, regulations, etc., or internal: Reflecting the limitations of the research or the system's available resources.

The solution of the system, Eqs. (1)–(3), would have amounted to a simple enumeration of the highest paying projects (i.e., those with the largest $E_{it}=G_{it}+V_{it}-Cit$ for every annual budget, U_t). A constrained budget of the type shown here would have required a more elaborate selective enumeration such as Branch and Bound, provided of course that all the data about the parameters G, V, C, and the constraints F are available.

The mathematical representation of this problem is quite straightforward and so is its solution for a given value of its

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parameters and constraints. A difficulty arises, however, when the analysis of the available research alternatives out of an infinite number of undefined research tasks has to be performed. Then, it is practically impossible to assign a quantitative value to the contribution of each possible research alternative, especially when the value of some of them is the contribution to a basic pool of disciplinary knowledge. Finally, there is practically no way to identify all constraints when some of them depend on the researcher and his organization, and not on the sponsor.

All of these difficulties are compounded by the fact that the life span of a research project; its development, implementation, and fruition may cover a long time-period, possibly 8–10 years or more during which various changes might be anticipated—in the annual research allocation, the inventory of research projects, and in their parameters. The sponsor, therefore, needs a strategic research plan with the relevant planning horizon of some 8–10 years, which identifies worthy research areas and their priorities.

The literature available on the development of strategic plans and related subjects, does not offer much help for the development of such a plan. However, we will review it briefly.

The literature about general strategic planning (Mintzberg 1994) and its application to construction (Warszawski 1996) involves mainly conceptual analysis of business competition and is not related to the present study.

The related area of technological forecasting concerns itself with the identification of emerging trends—technological, social, and economic (Toffler 1982; Abudayyeh et al. 2004; Bakens 1997; Naisbitt 1982; Cetron et al. 1988; Warszawski 1994; Schrover 2003), which influence the nature and scope of the supply and demand of products and services. Some of these trends can be measured, such as the cost of energy in EIA (EIA 2005), or other quantitative trends in other publications (Markandya et al. 2002; Britannica; Lyman and Varian 2003). The main body of forecasting literature concerns itself, however, with the assessment of changing demand by examining statistical mathematical dependence between these values and their leading indicators in the market—the emerging trends or change drivers (Makridakis 1998). Some of the concepts addressed there will be used in a later section in the study for identification of multidisciplinary sectorial problems.

Much more relevant for our case are the nonquantitative methods of public decision making (Lamford 1972). They employ various techniques for eliciting preferences from individuals and groups of experts. Finally, a considerable number of publications review knowledge needs in the specific areas included in our study. A wider review of these sources is contained elsewhere (Abudayyeh et al. 2004; Bakens 1997; Carr and Maloney 1983; CIB 1998, 2005; Ibbs 1986; NIST 2004; U.S. DOE 2002; Rogge and Tucker 1987).

Therefore, it is evident that the identification of the research items and their possible economic and social contributions remain the key issues to be addressed in the strategic plan that is being developed here. Consequently, the following methodology has been devised with respect to the strategic planning of research in building.

The parametric variables, the possible candidate research studies, will be identified and ranked by a rigorous evaluation process. Two methods will be employed for this purpose, one using the disciplinary approach and the other is oriented toward sectorial problem solving tasks. The contribution of the method suggested here is in using an elaborate grading process that reflects the interests of both long range knowledge building and its immediate problem solving capacity. The satisfaction of constraints is solved by basing the candidate detailed research items on the researchers' proposals, which by their proper definition ascertain their feasibility, and by selecting the group with the highest scores that fits within the annual budget. The viability of the method is secured by a rigorous adherence to the objectivity and accountability of the process.

Scope of the Study

The main knowledge required for the design, the construction, and the operation of buildings to be advanced by means of research can be divided into five main disciplines, following the classification customary in the engineering schools and in the international information exchange activity.

1. Structural engineering: Concerned mainly with the strength and stability of buildings and their components.
2. Building materials and technology: Deals with the examination and improvement of building material properties and durability, their production, and installation in structures and buildings, as well as with the development of new building materials and technologies.
3. Geotechnology: Deals with properties and behavior of the different types of soils and rocks and with their interaction with foundations, buried structures, retaining walls, and with various other civil engineering structures and construction works.
4. Construction management and economics: Deals with the realization of a building and its operation, including the attention to their total managerial, economic, and engineering aspects.
5. Physical performance of buildings: Deals with the various physical attributes of building performance, integrating between the user needs (for safety, health, and comfort) and the building and its components.

This scope excludes the aesthetic, cultural, and functional aspects of the building, which in Israel, as well as in most other countries, are pursued in the departments of architecture. Their research is funded through separate research budgets.

Nature of Research in Building

Research is usually defined (Oxford dictionary, Encyclopedia Britannica and others) as a methodical process of knowledge advancing. A distinction is sometimes made between applied research, the objective of which is to solve problems of production, health, education, etc., and basic research, the purpose of which is to explain nature phenomena without a specific application purpose. This distinction is not valid for industrial research, the ultimate purpose of which is always the application. Here, the distinction between basic and applied research refers more to the span of time rather than to the possible implementation in practice. This span of time may indicate, for example, whether the research is used to offer a solution to a current problem within a relatively short period of time, or to enhance the present knowledge on the subject (by creation of data bases, solution algorithms, etc.) as a prerequisite for the preparation of an industry code, or for the mitigation of a foreseeable future problem. The latter still has to undergo lengthy technological and institutional examination, and its application span will be, therefore, considered as a long range.

Industrial research is characterized, therefore, not necessarily by the ultimate purpose of its application, but by the immediate-

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ness of its applicability. Special features of research in general and of industrial research in particular are:

1. An extensive current literature survey of the topic, exploring all available sources, including:
   - Academic and professional publications;
   - Seminars and conferences;
   - Internet;
   - Direct communication with local and international experts; and
   - Visits to building sites and production plants, where relevant.
2. Objectivity, which expresses itself in:
   - Examination of as many as possible methods for solving the problem and a choice of the most reliable one;
   - Objective analysis of all data sources; and
   - Careful reliable measurement of inputs and outputs in each research solution.
3. Novelty: Using the most recent equipment, data, and computational tools, as well as extending their capabilities as much as needed, or alternatively developing new tools to achieve the research goals.
4. Contribution to general knowledge: It is expected that any research, even when applied to a unique problem, will (due to the amount of information processed and the rigor of the analysis employed) generate some generally valid knowledge, which can be easily identified and reemployed in other cases.
5. Exposure: Presentation of the research method, findings, and conclusions in appropriate professional forums in order to receive comments and critiques. In the course of the presentation, special emphasis is placed on limitations, i.e., the cases when the research deviated (out of necessity) from the principles outlined above; and the influence of these deviations on the reliability of the findings is discussed. This feature applies more to publicly sponsored research rather than industry sponsored research where the exposure may give an unjustified advantage to a competitor.
6. The systems approach, which consists of:
   - Developing a model for the problem-related system and definition of the objectives and their attainment criteria;
   - Identification of all significant system variables, such as factors, controlled and noncontrolled, which affect the problem solution;
   - Identification of constraints on output products and input resources. The constraints are determined in view of the research sponsor's stipulation (research brief), pertinent code and specification requirements, zoning regulations, prevailing rules and directives, etc.; and
   - Determination of values for all controlled factors in view of the constraints in a manner which will assure the optimal solution to the problem.

Many engineering-type investigations may include some or most of these features as well. However, in the absence of Feature 4, contribution to general knowledge, the investigation cannot be regarded as research, while in the absence of any one of the other features; it may be criticized as deficient research.

Given that proper research includes all six characteristics, the differences between the research work and a regular engineering investigation are as shown in Table 1. Apparently, using research to devise a solution for any specific engineering problem will be more expensive and will take more time than applying a regular engineering design procedure. It may be expected, however, that the solution so obtained will be superior in terms of its quality, depth, operation, reliability, or other pertinent effectiveness aspects. Moreover, the research-based solution will usually provide more general tools for solving the generic problem enabling its application in various cases, whereas the engineering-type investigation will be limited to the specific problem at hand. The feasibility of research application to any particular problem will depend, therefore, on the value of its tangible and nontangible benefits versus costs.

Table 1. Research versus Design Performance

Feature	Research	Engineering design
Up-to-dateness	Very high	Limited to few items
Objectivity	Highly pursued	To a limited extent
Measurement of inputs and outputs	Always measured	Selective measurement
Novelty	Always pursued	Addresses general state of art
Contribution to knowledge	Always	Seldom
Systems approach	To a large extent	Not necessary

Strategic Plan

From the operational viewpoint, the necessary outputs of this research study were: (1) devising a methodology for preparing a strategic research plan for an 8–10 years horizon; and (2) devising a procedure for preparing annual research programs that are based on the findings of the strategic framework.

A strategic research plan in building research should address two needs: Increasing the professional knowledge in the areas associated with building, and the generation of knowledge necessary for the solution of the current problems. The strategic plan, as developed here, and its application for preparation of annual research programs, is presented schematically in Fig. 1. The strategic plan is composed of three interrelated components. Two of them are knowledge bases, each containing all building-related knowledge, and the third is a set of procedures to be used by the research sponsor.

The two knowledge bases, although each should cover the same inventory of building-related knowledge, differ in the manner by which information is arranged in them.

One base follows the disciplinary classification. It stores the knowledge of the five major disciplines in a hierarchical manner on several (usually three) levels; each next level showing the disciplinary subjects at an increasing detail as shown in Figs. 2 and 3, with a total of 100–150 items at the lowest level in each primary discipline. This base reflects the academic and researchers' perception of the building-related knowledge.

The other base stores the knowledge by referring it to eight major problems of the building sector, which are subsequently related to some 30 tasks. This base reflects the general public viewpoint of the problem areas and the research users' perception of building-related knowledge. It is problem oriented and, therefore, interdisciplinary. Both knowledge bases, if properly compiled, will result in the same total knowledge stock, one of them attained by the systematic professional approach and the other by the operational approach.

The third component in the preparation of the strategic plan

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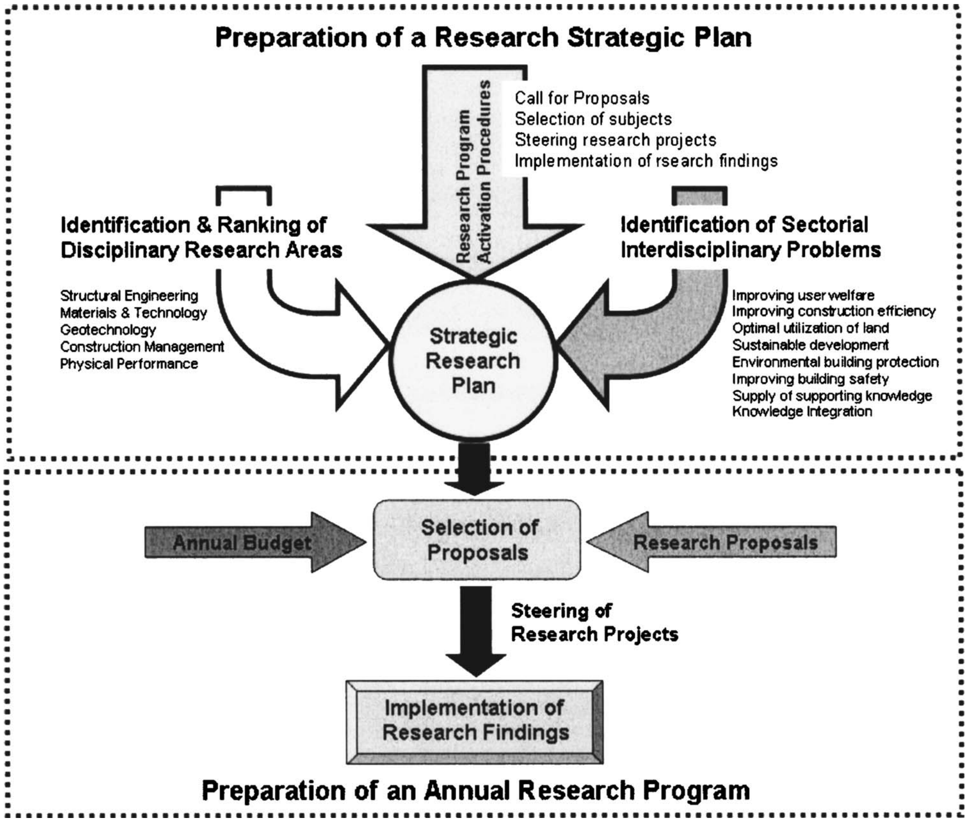

Fig. 1. The strategic plan

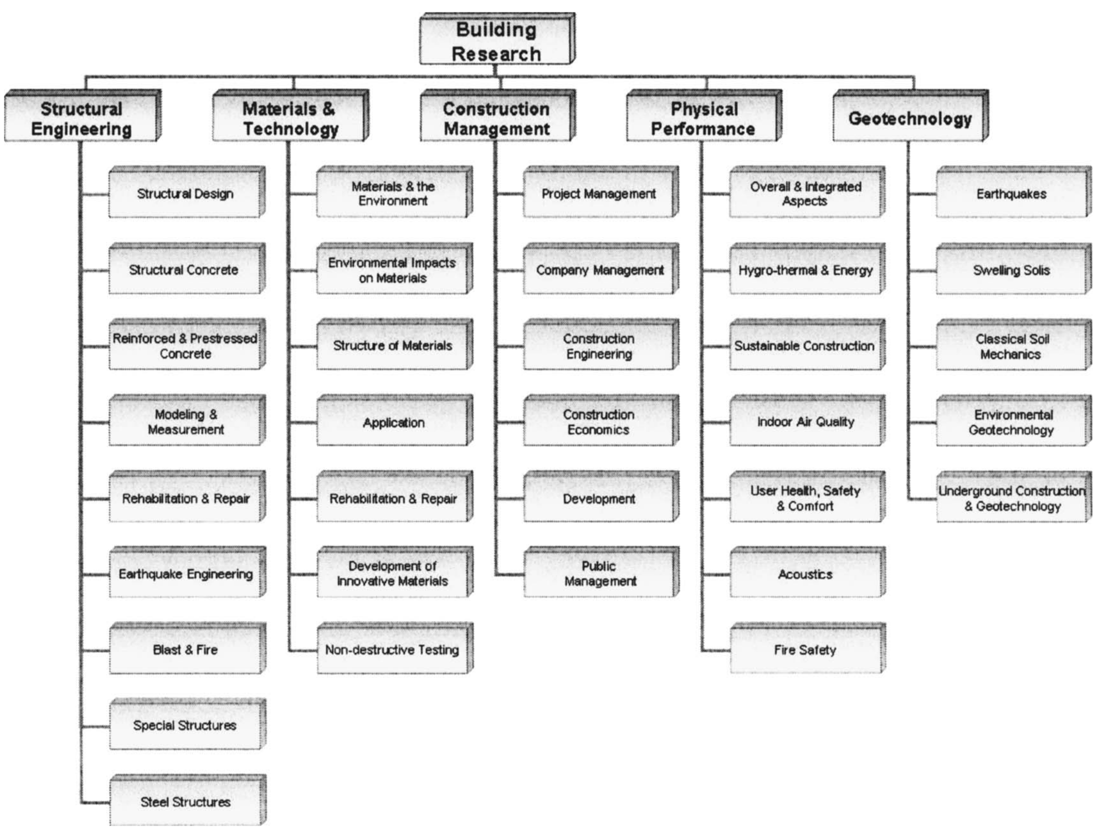

Fig. 2. The main structure of the disciplinary knowledge base

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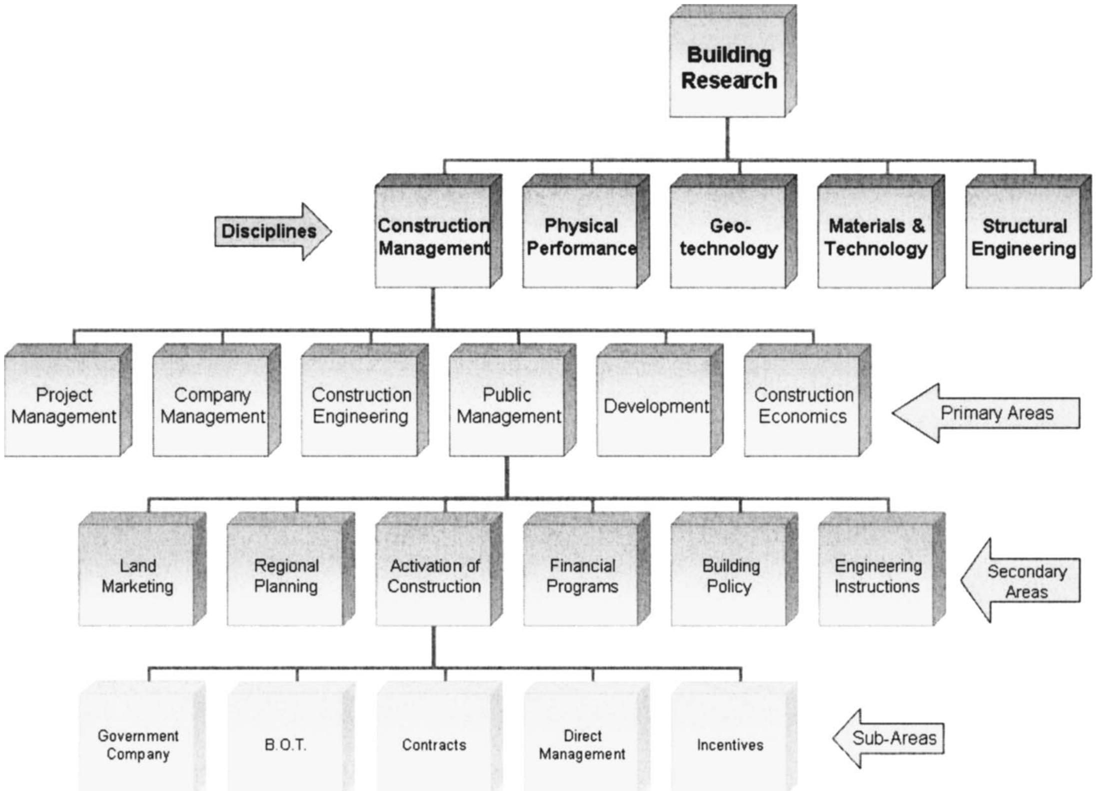

Fig. 3. An example of the hierarchical tree for one branch of the construction management discipline

was the set of procedures to be used during the planning horizon for the generation of the annual research program. The methodology employed for the three tasks above will now be presented.

Construction of the Disciplinary Base

A rigorous methodology for the construction of the disciplinary base employed in three stages is presented in this section.

Extensive Literature Survey of Potential Research Topics

The most promising search targets are:

- International publications dedicated to research, (research planning, research examination, research roadmaps, research agendas, etc.);
- Accessible lists of research topics being, having been, or to be executed by various academic institutes in the buildings domain, which are well known in the specific discipline; and
- The contents of academic journals and conferences reflected in the titles, and abstracts of their papers over the preceding 5–10 years. This search domain is particularly effective, since it should cover all the worthy research output in its discipline. One may assume that any potential research subject which has not been mentioned over the recent 5–10 years will be probably irrelevant over the whole forthcoming planning horizon.

Classification of the Acquired Research Topics

The classification was performed by means of the "product tree" method. It consists of a hierarchical division of the whole subject, in our case, the research discipline, into its components. The division reminds a tree trunk with main branches emanating from it. Each main branch has at its end secondary branches, and so it proceeds until the desired level of detail. Each branch represents, therefore, a certain component of its "parents"; the branch from which it grew, and in turn, is divided into secondary parts, its "off springs." The resolution can be controlled at each level by the number of off springs per parent and ascertain roughly equivalent size to all research items at each level. It can also help to ascertain that no research item is omitted and that there is no significant overlapping between items. Division in our case of each tree branch into three to seven secondary branches with common features, targets, or impacts resulted at the lowest level in 100–150 subareas per discipline. Each such subarea would then be contracted out by the sponsor as one or more research projects depending on his particular considerations and the research proposals submitted by the research community.

Several systematic methods for the generation of the product tree can be considered: It is relatively easy to construct the tree based on the building's physical components on various levels, e.g., main spaces, then assemblies, works, elements, and even resources. Each component can then be examined for its possible research needs in the given discipline. This simplistic approach, although following to some extent the design sequence, is not linked strongly to the research areas, and is less suitable for the methodical arrangement of knowledge.

Under a more rigorous approach, the tree's components can be examined also from the project realization aspect. Accordingly, each component would be examined in the context of different stages of realization, as follows.

1. Planning: First, a conceptual planning, later a general planning, and finally, a detailed planning,

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2. Construction/production: Design, contracting, erection, and measurement/control, and
3. Operation: Maintenance, performance, and decommissioning.

The combination of a component at a certain level with any realization stage generates a combination at which a problem that requires a solution may occur. Consequently, a systematic examination of a product tree with respect to all realization stages of its components/branches covers all the possible research needs. For example, a combination of a component window with a stage of operation/maintenance could create a research area dealing with the window maintenance, and one could then examine the need of research for this item.

Another method, more suitable for the identification of research subjects using a product tree focuses on the division of the total discipline into separate areas of work in research. For example, the construction management area could be divided into seven subareas as shown in Fig. 3: building economics, construction engineering, project management, company management, and development. These subareas could be later subdivided into secondary subareas and so on until the lowest level, where each branch can contain several research works with a common nature or content. So, for example, a subarea of build-operate-transfer (BOT) financing can include research projects which deal with the financing of BOT, risk management in BOT, application of BOT to office buildings, experience obtained with BOT projects in Israel, etc.

Independent of the method utilized for the generation of the product tree in a strategic long-range plan, it will not be useful to determine, at the beginning, the subjects of the individual research works, since these depend on the state of knowledge in the particular country or society, and on the specific problems that arise in the specific building market.

It was concluded that the division of each disciplinary knowledge base into possible areas and subareas of work accompanied by the ranking, which is described in the next section, fulfills well the sponsor's needs in the preparation of a long-range research plan, while utilizing the most appropriate terminology from the researchers' point of view.

Determination of Preference Ranking

Ranking of the identified research items certainly could be considered as the most important and most difficult part of the strategic planning. The obvious urge to base the ranking on the quantitative analysis of the cost benefit of the competing items proved to be impractical as a general guide, mainly due to the difficulty of assessing the benefits, assessing their implementation, and the probability of the attainment of these benefits. This important point is explored below, in a dedicated paragraph in more detail.

It was decided, therefore, to derive the rankings of the research items by sampling opinions of the two most prominent users of their results: The industry experts and the members of the academic staff. The experts, which consisted of leading engineers in their disciplines, could be viewed as a sample of their industry segment. However, due to the heterogeneity of the market and the subjective preference of the participants, such a sample is not sufficiently reliable. It was decided, therefore, in order to enhance the outcome, to increase the number of participants as much as possible. To carry out a meaningful process of opinions exchange between the experts, discussion sessions were held with some 20–25 participants per session. A considerable effort has been exercised to structure the meetings by focusing the discussion on the most important issues for the strategic plan leaders without inhibiting the free expression of the experts' views. A two stage process followed: In the first stage, a 3 h session took place in the course of the knowledge acquisition process, explaining the purpose of the whole exercise followed by controlled brainstorming. Toward this meeting, a preliminary version of the hierarchical tree has been distributed. Following this session, the tree was modified and updated to include all the newly accepted components. In the second stage, the advanced version of the product tree was distributed together with the summary of the first session's outcomes to all the experts who participated in the first session, some additional experts, and academic members. Most of those who received the forms filled out the ranking questionnaires and their inputs served in the course of the final ranking.

The questionnaires addressed explicitly all the subareas, including those identified after the brain storming meeting. In order to minimize the difficulty inherent in ranking of largely unfamiliar subjects, the ranking has been limited to four options. The responders were requested to rank the subareas as follows: (1) subjects that they considered very important and urgent; (2) important subjects but without any particular urgency; and (3) subjects which at that stage were not considered as justifying their research costs. The fourth group consisted of subjects which the responder is not familiar with or does not understand and, consequently, was not able to rank.

The views of the academic staff, which included all the members of the Technion and other academic institutions related to a given discipline, were obtained in a similar manner. As mentioned above, in every discipline, 100–150 subareas were identified, discussed, and ranked.

Limitation of Knowledge Sources

It was mentioned before that the ranking of research subjects was based to a large extent on the opinions of the industry experts. However, it appeared that an excessive reliance on this factor must be viewed with caution. The main reason for this cautioning is the preoccupation of the practitioners, even very enlightened senior engineers, with their current pressing problems. When this is coupled with a limited acquaintance with less known technologies and a distrust towards anything untried that does not offer immediate results, one may expect a strong bias against any long-range knowledge research subjects.

As the number of industry experts participating in any discussion was limited (20–30) in order to allow each participant to express and explain his opinions, there is practically no room for a formal statistical correction of the bias.

It appears that engineers who did not have any prior exposure to academic endeavors did not always believe that research can be used as an engineering tool for devising a solution to a given problem. Consequently, subjects of a more basic nature, essential to the generation of an objective infrastructure for an applied research were sometimes given an inferior ranking, despite the fact that this could inhibit the future benefit to practice and to the solution of other subjects that were given a high priority ranking.

Another interesting observation was that some topics cited by participants as highly desired research subareas consisted in well known knowledge that is well documented and taught in learning programs of various institutions. The problems observed by par-

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ticipants within these subareas were caused in fact by the lack of sufficient familiarity with conventional knowledge and, therefore, did not justify any involvement of research.

For all these reasons, it was not correct to base the ranking evaluation exclusively on the results of the questionnaires and preferences voiced during the discussions. Certain adjustments had to be applied as it was obvious that the opinions of the respondents suffered from the aforementioned limitations. However, it should not place in doubt the cardinal importance of active participation of the ultimate user in research-related decisions. Their insight and experience bring an invaluable dimension to the knowledge acquisition process. An effort should be made, however, to eliminate some of the misunderstandings that were discussed before in order to make the knowledge elicitation process more reliable. This is a very important subject which, of course, deserves separate attention. However, it seems to be of great importance in view of the obvious desire of researchers in any industrial sector to know as much as possible about the preferences of the ultimate research consumers.

Interdisciplinary Research

A problem will be referred to as interdisciplinary if its solution requires knowledge from more than a single discipline. With this definition, each problem is interdisciplinary if dealt with by means of the systems approach, as explained earlier, since the systems approach requires the examination of a problem from all aspects. In the case of problems related to building programs, these aspects include the performance of buildings, the planning and structural design, the technology of prefabrication and construction on site, operation of the involved building components over all of their economic life, and their disposal or recycling at the end of their life. In the case of the whole building, examination of all these aspects requires involvement of all the related disciplines, and of some of them when dealing with a single building component.

However, in this context some differences between a building design process and interdisciplinary research should be noted. First, the situation well-known in design, where representatives of several disciplines in a team determine together, using a professional give and take process, the dimensions or a capacity of a building component almost never occurs in research. On the other hand, in research, applying an interdisciplinary approach for examination of a building-related problem does not require necessarily an across-the-board interdisciplinary research. If a senior researcher from a certain discipline investigates such a problem and needs knowledge from another discipline, he or she can attain it by self-study or by means of ad-hoc consultation with an expert from that discipline.

Although, for simplicity, we refer to the research studies of both types as interdisciplinary, it is only when the problem requires research solutions from several disciplines that a true interdisciplinary research study is required. A comprehensive study can identify most of the interdisciplinary problems of the building sector. One should remember, however, that not every interdisciplinary problem requires a research solution. It is necessary, therefore, to determine which of the building problems need an interdisciplinary research solution and which do not. In the following section, the method for analysis of benefit versus cost of a public research item is explained, and the methodological difficulties are examined. Later, we focus on global problems, the nature of which justifies an interdisciplinary research even without formal cost benefit justification. The problems are identified in an objective manner and afterward the major subjects to be addressed are discussed.

Determination of the Feasibility of a Research Study

The ultimate criteria for the attractiveness of a research study is the net benefit (expected benefit of a study less its cost) that the study is expected to render to the building sector. In order to assess this benefit, it is necessary to focus on the following factors:

- The expected benefit;
- The cost necessary to realize this benefit (development, production/construction, operation); and
- The probability that the benefit will be realized as expected.

In practice, an objective assessment of the net benefit of a research study relevant for public projects is difficult for the following reasons:

- It may be difficult to reasonably quantify the benefit from research projects which are intended to serve the public. This is especially so when the benefit is derived from stochastic factors whose objective assessment is impossible, such as the reduction in the number of fatal accidents, prevention of diseases, saving of time, etc.;
- It is almost impossible to measure the benefit of "basic" studies, which are supposed to yield a scientific infrastructure for other research studies;
- It is difficult to assess/predict the probability for the benefit realization, which depends on the nature of the solution and the conditions necessary for the realization; and
- It is difficult to assess the total cost of the research and development, mainly due to the fact that under local conditions there is a shortage in the required human resources necessary for this purpose. The cost in such a case should be determined not only on the basis of the actual investment in research man hours and other expenses, but rather, should reflect also the unachieved benefit of alternative research, which had to be forgone.

As attractive and desirable as it may be to rank research subjects on the basis of cost benefit analysis, this is actually unattainable because of all the reasons mentioned above. Under these circumstances, it is customary to view certain types of problems as total sector problems. For such problems, the promise to draw benefit from any type of improvement, even a small improvement, is very likely and evident to everybody, and can be noticed even without a formal consensus of the experts.

Characterization of the Building Sector Problems

With respect to the characterization of problems relevant to the total building sector, or "sectorial" problems, we can usually state the following:

- They pertain to total buildings and not merely to one component;
- They affect all or a significant portion of the buildings population;
- Their solution will clearly serve the needs of the entire society; and
- They are caused or accelerated by global processes. These processes are referred to as "trends", "change drivers", or "change engines". The preparation of strategic programs in

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Table 2. Interdisciplinary Objectives and Problems

Objective	Change-driver	Interdisciplinary global tasks	Comments
1. Improving building users welfare	Income per capita, education, consumption per capita.	Building quality. Maintenance of buildings. Upgrading of buildings. User comfort and health.	Thermal, Acoustic, IAQ, etc.
2. Improving efficiency of the construction process	Required extent of foreign labor; labor productivity.	Industrialization of building. Importing of labor/technological improvement.	Including novel building methods
3. Optimal utilization of land	Density per m^2. Extent of urbanization.	Policy of land marketing. Tall buildings. Underground building. Building on problematic sites.	Soft land, steep slopes
4. Sustainable development	Increasing electricity consumption; cost of pollution.	Energy saving in buildings. Recycling building materials.	
5. Protection of buildings from environmental damage	Cost of building defects.	Protection from land swelling. Support of slopes. Strengthening of land. Supporting and stabilizing of slopes and strengthening of land. Protection of the building envelope.	Including moisture protection
6. Improvement of building safety	Safety from natural and man-made disasters.	Earthquakes. Fires. Hostile activities. Strengthening of existing buildings. User safety. Safety on the construction site. Advancement of useful design savings.	
7. Supply of supporting knowledge	Increase in information. Increase in Internet aids.	Gathering and evaluation of knowledge.	
8. Integration and implementation of knowledge from other fields	The cost of computer services.	Automation of construction. Automation of control. Automation of design and planning. Manufacturing methods for building materials and elements. Automation of production of components and materials. Intelligent control systems.	

any area requires exploring the future with available forecasting tools. The technological forecasting usually employs an objective process which identifies first, the change drivers, and then, examines the influence on a given economical or sociological sector. The emergence of technological forecasting as a valid discipline received a large boost from two popular but very influential books (Naisbitt 1982; Toffler 1982), which were published two decades ago, and dealt with the analysis of the evident and emerging trends on the life pattern and the supply and demand of products and services.

In many of the cases, a strategic plan that is prepared for a certain organization relies on the specific objectives that this organization wants to attain. These objectives are determined by a consensus of experts or decision makers, and are translated later into tasks in a desired extent of detail. An example is the development plan for the American concrete industry named "Road-Map 2030" (U.S. DOE 2002).

The approach which was implemented in our study in order to identify the interdisciplinary total building sector problems combines, in effect, the main characteristics of both approaches mentioned above. The determination of these problems was based on the desired objectives of the building sector, as they were identified in discussions within the research team and with others. It was also based on the economic and social reality pushing for their attainment, as it is expressed in various change drivers, which will be presented below. The ultimate list of the total building sector problems in Israel, which is presented in Table 2 and discussed below, was formed in its preliminary version, with the aid of the six disciplinary seminars with practice experts. Subsequently, the conclusions of that stage were discussed within the research team and classified according to the main objectives of the Israeli building sector, and verified by the identification of the change engines which cause them. The list shaped in this manner

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Table 3. The Stages of an Annual Research Plan

Stage	Input	Output	Decision premises
Call for proposals	Proposal instructions	Submitted research proposals	Call to include all information required in a proposal and its grading process.
Evaluation and grading of proposals by a professional panel	Research proposals	Grading of proposals	All panel members (1–3) must fully understand the objective and the methodology of the research study.
			Evaluation reasoning must be documented.
Allocation of budget to winning proposals	Proposal grades. Total budget	Annual plan	Priority in allocation by grading only. Other sponsor considerations must be objective and published in advance.
Steering of research work in progress	Research plan	Final report, and implementation plan	Steering committee members should understand all details of research method and the implementability of results.
			The intermediate steering reports, 2–3 per year, must address explicitly the adherence to method, adherence to schedule and, usually in the final steering report, the emerging implementability of the study.
Completion		Final report.	
		Implementation plan.	

was presented for a final discussion by an interdisciplinary team composed of experts in the various areas.

Interdisciplinary total sector problems were grouped according to their respective objectives into eight groups as follows:

1. Improving building user's welfare;
2. Improving efficiency of the construction process;
3. Optimal utilization of land;
4. Sustainable development;
5. Protection of buildings from environmental damage;
6. Improvement of building safety;
7. Supply of supporting knowledge; and
8. Integration and implementation of knowledge from other fields.

A short review of these sectorial objectives, their change drivers, and consequent interdisciplinary tasks follows in Table 2.

Special attention has been given to the mutual consistency of the two bases. Both of them handle basically the same information albeit from different angles—one is more concerned with the acquisition and advancement of knowledge, while the other with the problem solving aspect. Obviously, any multidisciplinary task must be eventually divided when examining its knowledge needs into disciplinary components, and the needs of each of them should be reflected in an appropriate set of subareas in the disciplinary base. Such matching test has been done within the study with respect to each of the 30 problems in the interdisciplinary base.

Procedures for Preparation of Annual Research Programs

The preparation of the strategic plan included also the establishment of procedures for preparation of the annual research programs in the planning horizon. The procedures encompass the call for proposals, the method for selecting the proposals to be effected, the steering of the research studies, and the implementation of the findings. It is assumed that the technical details that were devised with the plan are not of interest to readers in a different country, and, therefore, the following review addresses mainly the more general aspects including various stages of the activation of the annual research program, their objectives, and main premises.

Three general principles guided the procedures development: (1) there should be some well understood benefit associated with the outcomes of research studies performed under a given annual plan; (2) the method for generating the annual program should be reliable and transparent; and (3) the implementation of this method should be simple.

The consistency of decisions over the planning horizon has been provided by the two knowledge bases: The disciplinary, which refers to the accepted knowledge classification ranked for the entire strategic horizon, and the interdisciplinary, which addresses the sectorial objectives and problems. The latter base can be adapted to the sponsors' changing preferences by allowing them to establish in every annual call for proposals the subjective weights they attach to the interdisciplinary objectives. These weights would usually be in the range of 0.80–1.20.

The annual program activation stages were defined as follows:

1. The call for proposals: Giving a full knowledge about the preferred study subjects, the required qualifications of the proponents and the selection criteria, as outlined below.
2. Submittal of proposals.
3. Grading of the proposals by a panel, where the grade of a proposal is compiled from the following parameters:
   - The ranking of the subarea best conforming to the proposed research study;
   - The weight attached by the sponsor to the sectorial problem served by the proposed research;
   - The benefit potential of the issue, unique to the proposal;
   - The professional stance of the proponent and the affiliated institute;
   - The clarity of the research method; and
   - The quality of the proposal.
4. The steering of the study execution by a committee.

The general premises of each stage are summarized in Table 3.

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Table 4. An Illustration of the Grading Process of a Building Research Proposal

Grading parameter	Grade awarded	Arguments	Contribution to grade
Disciplinary ranking	10[a]	Rank 1[a] according to preference code in Construction Management knowledge base (see Table 5)	10
Relevance and specific contribution of proposal outputs to sub area and to problem solving capacity	8[b] on a 2–10 scale	The cost-height relation is considered an important factor in the advance of tall buildings in urban zoning regulations	8
Quality of submission	7[b] on a 2–10 scale	Good and effective description of method and outputs	7
Research infrastructure	8[b] on a 2–10 scale	The proposing research team and institute have a good record of several very high quality economic studies	8
Continuity	9[b],[c] on a 2–10 scale	The proposed study is a second stage of a study on structural design of tall buildings highly recommended by its steering committee	9
Subtotal			42
Direct effect on an interdisciplinary objective	(1.1–1.0) of the subtotal	The Rank 1.1 from the annual ranking of the interdisciplinary base (see Table 6)	$0.1\times 42=4.2$
		Total grade of proposal	46.2

[a]Rank-grade relations are as follows: Rank 1—Grade 10; Rank 2—Grade 5; Rank 3—Grade 0.

[b]The Grading Scale: 2,3—Unacceptable; 4,5—Moderate; 6,7—Good; 8,9—Very Good; 10—Excellent.

[c]When not a continuation of a previous stage: Grade 5.

The information that should be employed toward the preparation of the annual research plan includes:

- A list of subareas in each discipline;
- A list of interdisciplinary total sector problems discussed above;
- The weight in the range of 0.8–1.2 to be given by the sponsor to each interdisciplinary total sector problem according to the specific preferences in this particular year; and
- The call for proposal procedures as outlined below.

The call for proposals, which would refer to an annual plan derived mostly from the strategic plan will include the following items:

1. The weight of the interdisciplinary total sector problems as perceived by the sponsor for the particular year.
2. Qualifications of the applicants and of the respective research institutions.
3. The deadline for proposals submitted.
4. The contents of a proposal.
5. The method for the selection of proposals to be executed.
6. The steering of the research projects.

The example shown in Table 4 illustrates the grading process of a typical proposal titled "the cost–height ratio in residential buildings".

Conclusions and Recommendations

The objectives of the study were as follows:

1. To devise a methodological framework for the preparation of a strategic plan for the applied research in the building domain.
2. To prepare a strategic plan for the activation of research in the planning horizon (8–10 years).
3. To prepare procedures for using the strategic plan as a basis for annual research plans in the planning horizon.

The study's scope included buildings and their vicinity, and the knowledge required for the advancement of the main engineering disciplines related to it. These disciplines are structural engineering, materials and technology, geotechnology, construction management, and physical performance of buildings. The study has been performed in close cooperation with the parties in the building sector who are expected to benefit by it.

The main findings and recommendations of this study are:

1. A major purpose of research in building is to offer solutions to problems which require special solution methods due to their complexity or size. In this context, one can view research as a tool which enables to offer improved and innovative solutions that are more efficient and reliable to managerial and engineering problems than those applied previously.
2. Consequently, research can fulfill two important roles:
   - To prepare the infrastructure of data, procedures, algorithms, and explanations which enhance the present knowledge and create a basis for solution of major and complex problems that are expected to occur in the future; and
   - To prepare the infrastructure for the solution of current specific problems, which involve a large number of buildings or even the whole building sector. Such studies are valid when the benefit of their outcome will exceed the additional resources necessary for the research.
3. The strategic plan of research in building must respond, therefore, to two main needs: Improvement of knowledge in different professional areas related to building, and generation of knowledge required for the solution of interdisciplinary problems in the building sector.
4. The study defined the research needs and their priorities in five professional disciplines, as follows: (a) Structural engineering, (b) materials and technology, (c) geotechnology, (d) construction management, and (e) physical performance of buildings.

   Each one of these disciplines has been divided into primary areas, and at a higher level of detail to secondary areas and subareas. Some 100–150 subareas have been identified for each discipline. Each subarea received as priority rank of its research needs one of three values: (1) Important and

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urgent; (2) important, but not urgent; and (3) unnecessary at present.

5. Thirty interdisciplinary sectorial problems were identified, which due to their size and severity justify investment in research and development for their solution. Each of the problems could be related to one of eight society sectorial objectives, which would be served by its solution. These are: (a) Improving building user's welfare; (b) improving efficiency of the construction process; (c) optimal utilization of land; (d) sustainable development; (e) protection of buildings from environmental damage; (f) improvement of building safety; (g) supply of supporting knowledge; and (h) integration and implementation of knowledge from other fields.
6. The importance rating of these objectives will depend on the prevailing circumstances and current needs. Consequently, their rating should be determined for each annual plan by the research sponsor.
7. The process of generating the annual research program should be performed in an objective manner clear to everyone. In order to achieve this, the following principles must prevail: (a) The call for proposals should include a full exposure of the sponsor's objectives, the criteria for the selection of proposals, and the information to be supplied by the proponent; (b) the grading of proposals should be performed in an objective and easy to understand manner; (c) steering of the study should be lead by acknowledged professionals, and (d) upon research completion, implementation of its recommendations should follow in accordance with a prearranged plan.
8. The criteria for grading candidate research proposals within the framework of the annual budget are as follows: (a) Rank of the subarea closest to the subject of the proposal; (b) specific benefit of the proposal and its contribution to knowledge and practice in the building sector; (c) clarity of phrasing in the items of objective, method of study, and the possibilities of its implementation; (d) the research infrastructure: The knowledge, proficiency, and proven experience of the chief researcher and the institute of which will house the research; (e) the being of the proposal, a natural continuation of a preferred multistage research project, or of a research which was recently completed and considered as very successful; (f) the conformance of the proposed study to a particular sectorial problem and its current rating; and (g) the grading will be shown to the proponent if he asks for it.
9. The strategic plan includes, therefore:
   - The hierarchical presentation of building knowledge with the ranking of all its subareas;
   - A list of interdisciplinary problems and their coverage by the disciplinary subareas; and
   - The procedures for grading of research proposals.

Updating a strategic plan should be done once every 8–10 years. It will examine each of its premises and their evaluation in the light of technological changes and the change in the needs of the building sector (Tables 5 and 6).

Table 5. Grading Example—Extract from the Construction Management Disciplinary Base

Discipline	Primary area	Secondary area	Subarea	Rank
Construction management	**Building economics**	Feasibility study	Cost of capital	
			Risk management	2
			Economic life cycle	1
			Methods of investment analysis	2
			Economic analysis of building systems	2
		Cost-benefit analysis	External costs	2
			Costs of sickness and injury	2
			Value of life	3
			Multi-objective decision-making	2
			Measurement of economic activity	2
		Econometric models	Supply and demand models	2
			Production functions	2
			Input-output tables	2
		Life cycle cost	Maintenance cost	2
			Energy costs	2
			Cost models	2
			Recycling models	1
		Optimization of design	Effect of building shape on cost	1
			Underground buildings	1
			Tall buildings	***1***
			Optimal selection of elements and materials	2
			Value analysis	2
		Financing of building works	Financing methods	2
			Capital structure	2
			Financial ratios	2
			Cash flow analysis	2
	Construction Engineering	Construction methods		

Note: The proposal belongs to subarea of "Tall buildings" under secondary area "Optimization of design," which is under the primary area "Building economics" of the "Construction management" discipline (as indicated by the bold fonts) and its rank is 1.

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Table 6. Grading Example—Extract from the Annual Interdisciplinary Base

No.	Objective	Interdisciplinary global tasks	Rank
2.	Improving efficiency of the construction process	Industrialization of building. Importing of labor. Technological improvement.	1.0
3.	**Optimal utilization of land**	Policy of land marketing. **Tall buildings**. Underground buildings. Building on problematic sites.	1.1
4.	Sustainable development	Energy saving in buildings. Recycling building materials.	1.1

Note: The proposal belongs to Objective No. 3 "Optimal utilization of land" (as indicated by the bold fonts) its rank is 1.1, and its multiplier is $(1.1-1.0=0.1)$.

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