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Human Error in the Building Process — A Research Proposal

Erreurs humaines dans les projets de construction — Proposition d'un programme de recherche

Menschliche Fehler bei Bauprojekten — Vorschlag eines Forschungsprogrammes

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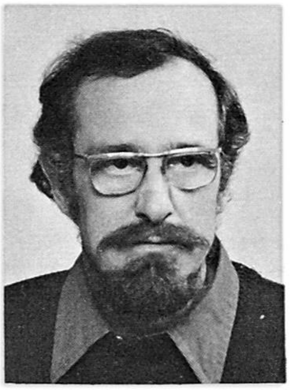

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SUMMARY

The importance of human or gross error as the cause of a majority of damages and mishaps in construction is discussed. A research programme is proposed and methods outlined for the study of the parameters related to human error. Methods proposed include a logical/semantic analysis of the parameters, and a model of the building process for the analysis of data from practice, and for the development of a strategy to counteract gross errors and their consequences.

RÉSUMÉ

L'importance de l'erreur "humaine" ou "grossière" est discutée en tant que cause de la majorité des dommages ou accidents dans la construction. Le programme de recherche proposé comprend les méthodes pour l'étude des paramètres reliés à l'erreur humaine. Les méthodes proposées comprennent une analyse logique et sémantique des paramètres, ainsi qu'un modèle du processus de construction pour l'analyse des données et de l'expérience provenant de la pratique ainsi que pour le développement d'une stratégie contre les erreurs et leurs effets.

ZUSAMMENFASSUNG

Die Rolle der "menschlichen" oder "groben" Fehler als wichtigste Ursache von Schäden und Unfällen im Bauwesen wird besprochen. Ein Forschungsprogramm wird vorgeschlagen und Methoden beschrieben für das Studium der Parameter, mit denen der menschliche Fehler zusammenhängt. Die Methoden bestehen aus einer logisch-semantischen Untersuchung dieser Parameter und aus einem Modell des Bauvorganges zur Verarbeitung von Daten und Erfahrungen aus der Praxis, und zur Entwicklung einer Strategie gegen die groben Fehler und ihre Folgen.

PREFACE, ACKNOWLEDGEMENTS

The present paper was first submitted as a research proposal to the National Research Council of Canada for the purpose of initiating a research programme. It is the result of some years of intermittent discussions among a group of engineers interested in the problem of human error in building. Many have contributed ideas and valuable suggestions, and have assisted in seminaries and meetings, mostly at their own expense. The author wishes to make it clear that the text is but a summary of his perception of the present state of cristallisation of these ideas; the original of most of them cannot be traced back to any particular individual but has evolved in time, and will have to evolve further if tangible results ought to derive from this endeavour.

Among the many collegues who helped him along, the author wishes to extend his particular gratitude to David. E. Allen and Carl J. Turkstra for their cooperation and criticism. He also wishes to appreciate the help of Neil FitzSimmons whose work with the "EPIC" programme has proved of great value to the task and will do even more so in the future.

An extensive bibliography was compiled through the work of two graduating engineers at McGill University, N. Beylick and J. Poissant at the end of the year 1981, who have scanned the available literature for publications relating to the subject. The bibliography is not reproduced here as it would exceed space limitations. It can be obtained from the author. No particular reference is made in the text of the report to any paper as it is not possible to justly appreciate where precisely ideas and suggestions have originated or been reinforced.

The writing the first report version was supported in the framework of an initial research contract by the National Research Council whose officers the author wishes to thank for this opportunity. It is hoped that the work will bear fruit in further years of research.

1. INTRODUCTION

Human error has been found to be at the basis of a great majority of failures, and in particular failures of structures. Estimates of the proportion of failures which were caused directly by human shortcomings range from some 70% to practically all that is going wrong in construction, the remainder being associated with such concepts as "statistical deviation", "calculated risk", or "acts of God"; some of which, if looked at a little closer, can also be traced back to some human action or inaction which, if carried out more adequately, would have helped to avoid the mishap.

Recent major disasters are still vivid in everybody's memory such as the Hyatt Regency Hotel in Kansas City where a seemingly insignificant detail was badly designed and caused death and injury to many.

Other instances such as the numerous roof failures under snow load in the North Eastern North America in 1971 are perhaps less spectacular but have cost enormous amounts of money for repair, replacement and damages caused by the failures. Most of the cases could be traced back to the failure of designers to consider exceptional snow loads in the dimensioning of the structure through ignorance, erroneous information or negligence - in many cases snow loads causing failure did not exceed the design values (unfactored) specified in the Building Codes of the time.

Numerous other failures occur during construction, due to temporary instability of falsework, lifting devices etc., mostly without even surfacing to public knowledge except where human individuals are hurt or killed or other features make the accident newsworthy. It is estimated that on the average each project costs from 1% to 5% more due to mishaps, failures, accidents etc. which are being absorbed within the construction budget as normal contingencies but which could have been avoided if only the right people at the right time had acted more aptly.

Failures do affect other features of building than the primary structure; e.g. a major proportion of brick facing built in the past 10 to 20 years in Canada and the Northern U.S. have to be repaired, replaced or rebuilt due to the phenomenon of creep in concrete. The elements of this have been part of our knowledge for many decades - only it was never applied as a design principle except very recently when the failures became so frequent and severe as to amount to a major disaster, and thereby arousing everybody's attention.

It is variously estimated that all failures and damages in building amount to 2 to 5% of the total construction cost. This, if applied to a country such as Canada with a construction budget of $28 Billion or so per year, would amount to an additional bill of one half to over one billion dollars each year, or some $20 to $40 per inhabitant per year.

It is obvious then that, if means could be found to reduce the proportion of this penalty for human shortcoming, their institution would be a paying exercice indeed.

The precise nature and functional relationships of human error have so far eluded attempts to explain and analyse it, beyond the limits of what is generally called common sense.

Attempts at a classification of the diverse expressions an error can assume, have yielded such categories as "ignorance", "negligence", "lack of attention", "communications breakdown", "responsibility gap", etc. None of these descriptive names can command more meaning than that of a general statement highlighting what is thought to be the most decisive feature in the chain of events.

Attempts to classify on the basis of concepts more strictly defined have sofar only been tried on "topographical" aspects of failures such as distinguishing where the error was committed (during design, in construction or in the usage etc.), who was presumably at the origin of the error (engineer, contractor, supervising authority etc.) or other, more mundane aspects such as the cost of repair, or the physical characteristics of the accident. Human error as such has never been the subject of serious and scientific analysis.

This paper attempts to outline a more direct approach to precisely the question concerning the nature and charateristics of human error in all its aspects. A combined research effort is envisaged, using data already collected on the description of mishaps, and scientific methods to systematically study characteristics, origin and perpetuation of errors. Eventually, on the basis of insight gained, strategies can hopefully be developped to counteract human errors and their consequences, reducing the loss which is currently being incurred by society because an undue amount of things are going wrong in building industry.

While it is quite clear what the benefits will be if successful strategies are found to reduce human error, it is less evident who will be the beneficiary, in a more specific sense than "society as a whole".

Obviously, the first line of actors affected are the direct participants of the construction process: architects, engineers, tradesmen, workers, contractors, owners, building officials who bear the first and immediate brunt of a mishap, or are even bodily involved in it. Accidents of lesser scope will be borne entirely by those immediately involved but they willin turn, in the framework of common consensus, pass it to the further layers of society in the form of contingency margins on fees, etc. In the case of more spectacular single events, insurance companies will step in to take over the coverage of the loss, acting as brokers and backcharging it to the participants in the form of premiums. Eventually, society as a whole will indeed bear the loss in its entirety whichever name it assumes between intermediate stations: In the final account it will always result in a loss of productivity, value of property, or in extreme cases, of human life.

On the other hand, society is notoriously unaware of the particulars of its own incentives if they are farther removed than the fool or tax bill. It will therefore be rather arduous to bring to bear the motivation of the real beneficiary, i.e. society; and this has certainly been one of the principal reasons why research on the subject has been slow in coming.

2. TRADITIONAL STRATEGIES

The fact that structural safety depends very directly on the risk of gross error, has always been recognized by the people practicing design and construction, more or less consciously: the answer was invariably to institute mechanisms for checking, control and supervision. The great diversity that exists today of different checking methods, arrangements and institutions, reflects an equivalent degree of uncertainty about which version would be the most efficient. It is very interesting to note that in some countries (e.g. Germany) an extensive state controlled institution called "Prufingenieur" is being operated at great expense to control the incidence and consequences of gross errors in design. Elsewhere, insurance companies (e.g. France) take control of this function, instituting their own organization for checking and supervision. In countries like Switzerland or Canada no such institutions exist at all, except for projects where the state itself acts as the owner/builder, i.e. in public projects. Many different arrangements exist and no proof has been proposed sofar to the effect that one system of checking were superior to another, i.e. by further reducing the incidence of accidents or structural insufficiency.

It is important to note that every one of the systems in use today, institutionalized or not, has evolved on the background of the practical experience in the particular country, and suiting its social and economic, as well as professional tendencies, but apparently without any rational connection to the problem and its characteristics.

The performance of the checking activity is based on common sense, the term used here for the entirety of concepts and relationships commonly accepted among informed professionals. Common sense in this definition may become supplemented in the individual case, by the personal experience and judgement of the people in charge but it can be seen quite clearly that the limitations on the thought-process representing the checking are quite severe. They have probably not changed in essence since the early history of building. No rational or consistent approach exists as yet to indicate where and how to apply resources: It is not known beyond the judgement of individuals involved, at which point(s) in the building process it is most efficient to set-up control positions for checking. Cases can be cited where present day practice violates even the rather trivial principles accessible to common sense reasoning: e.g. It is quite normal in North American Building practice to assign a sizeable proportion of the resources available for checking, control, etc., to the testing of concrete cylinders, in obvious disproportion to the relatively modest importance of the strength development of the concrete as delivered to the site before placing. No concept exists however, which would justify to change this to a more proportionate allotment since the importance of the particular building parameter cannot presently be quantified (e.g. by the value recuperated through elimination of damage). Therefore one is shying away from a change perhaps due to the all-present notion of "How am I going to explain to the judge, why I diverted from commonly used practice", in case something goes wrong.

Other examples from typical practice come to mind: it is quite obvious that the placing of reinforcing steel should be verified as late as possible, i.e. immediately before pouring the concrete. But this is not always practicable since it may already have become quite difficult and costly to correct an error. As well, common sense reasoning cannot answer the question of the qualification of the person who verifies the steel: Should it be the designer who will at the same time be able to catch some design errors of his own? Should it be the draftsman who made the drawing, or another engineer or draftsman?

Each of these possibilities presumably includes its special pro's and con's which cannot rationally be measured, weighted or compared. Therefore the case is usually decided on the basis of convenience, i.e. on a concept totally foreign to the purpose of the activity, namely the correction of possible errors.

In larger projects, especially where the creation of a great public hazard is feared like for nuclear plants, great dams etc., entire rulebooks are written about checking, control and supervision. At great expense to the client, the programmes are carried out and drawings going for construction bear dozens of signatures and stamps. This, however, does not mean that dozens of people have checked the drawing and above all, not at the right time. In extreme cases the procedure may in fact become quite counterproductive by creating the impression that nothing can be wrong if a drawing was checked by so many. The man who wrote up the checking procedure may actually have overdone his job by making the procedure so tedious and time consuming that everybody had to take shortcuts just to get the work done. Again, these shortcuts are not chosen to do the least damage to the entire project, but to accommodate the convenience of the moment, a concept completely different from the purpose of the checking. More harm than good may have been done therefore by the too extensive programme, in spite of good intentions and great expense.

Also, it is trivial to conclude that for every position to fill, the best possible man should be employed. Not everybody is a superman though, or ideally suited for a job and work will have to be done by people of lesser capabilities. Criteria must therefore be found to optimize personnel selection within the constraints of the case. Perhaps even entire organisational subsystems will have to be designed to suit the particular personnel situation, just like it is presently being done for smaller jobs where the key people running the job are assigned the duties best suiting their talents, and the description of an assignment may vary depending on the individuals in charge.

3. PRESENT STATE OF RESEARCH

The reasons for structural accidents and other types of insufficiency have been made the subject of intensive research activities since the 1950's. It was recognized early that the probabilistic concept of statistically measurable values of design parameters would promise to be a useful tool for some insight into the relation between those parameters and structural safety. Extensive literature exists today, to wirtness the efforts spent; and results have been put to practical use, in the form of a move towards more or less systematic revisions of Building Codes and Standards which one attempts to base on a set of consistent probabilistic principles. These are expressed for instance in the form of a measure of the theoretical probability of exceeding certain safety criteria.

It also became clear as a result of this research that good agreement could not be found between predictions of accident frequency based on statistically measurable properties of the design parameters (material properties, loads, dimensional quantities etc.) on one hand and the frequency of structural insufficiency "in the real world"*. A source of discrepancies other than probabilistic extremes of relatively great rarity must therefore exist which conclusion was reached persistently by many researchers starting in the 1960's, although no clear definition exists even today as to what exactly that source could be. Variably, concepts such as "human error", "gross error", "systems or organizational breakdown", "lack of knowledge","insufficient checking", "communication gap", etc. have been cited as possible descriptions of what really happens. All of them have in common that their definition is indistinct and fuzzy. Moreover they are interrelated and not at all mutually exclusive. A mishap may have originated from a communication problem, which in turn was caused by a bad personal relationship, and the error may have gone undetected because the organizational set-up had put a person with the wrong qualifications in the position of supervisor whose responsibility was not clearly defined etc. etc.

This description could be extended onto many other concepts and aspects. It is quite typical of the conditions leading to mishaps that they are logically complex, involving many parameters of diverse character, and from many fields of human endeavour. One property however, can be stated which is always present: It is the fact that the involvement of the human element removes the problem from the realm of statistical studies concerned with physical parameters exclusively.

More recently a catch-all function has been proposed to describe the risk of error of any particular case: The error-proneness. If one accepts this, the relationship of this function to the description of a situation and its parameters become the next element to be determined. Attempts to carry this out have not yet left the realm of the theoretical desk-studies, or academic discussions.

Another type of research has been undertaken starting from the collection of data on structural failures. Some of this data has been codified for purposes of computerized analysis, and reviewed vs. various concepts of contributing parameters such as a Swiss study which analysed some 700 failure cases with respect to cost, category of building, construction phase (including usage and demolition), the phase in which failure was detected, building elements affected, etc.

Other similar projects are still in stages more rudimentary than the above described exercise but will bear fruit eventually.

What is common to all of them is, that they concentrate on the hard, (physical) type of parameters rather than those related to organization, communication, motivation; it is

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* probabilistic extremes producing unsafe conditions are much rarer than are failures and damages.

those latter ones however which are closely associated with the generation and perpetuation of human or "gross" errors.

This is clearly leading into the field of the "soft" sciences and it must be recognized that without their contribution, an essentially human problem can never be solved. Research on human error must therefore adopt a truly interdisciplinary character as will be discussed below.

4. THE HUMAN ELEMENT IN BUILDING CONSTRUCTION

No structure or system is perfect. This applies to the final product as well as its generating agent, the process of building itself. Even the best possible management set up, the best conceivable communications and reporting system and the most meticulously thought-out responsibility chart will have faults, gaps and imperfections.

Where an organizational element or system is institutionalized, it will age with time, accumulating obsolescence and become less fitting for its purpose - if it is left to itself.

It will only be able to rehabilitate, to recreate, to recondition and to adapt itself if it is kept alive, i.e. if it is kept in continuous intercourse with its living elements. Where a system becomes too remote or unreachable for its users for example by becoming overly infested with bureaucratic procedures and regulations, its faults if discovered at all, will go uncorrected, and as time goes by, necrosis will set in and eventually the system will become unusable or outright dangerous.

Like in any living organism, the recreative and corrective functions will take place whenever or wherever required. If in biology the steering and driving agents for this are instructions created and passed on by diverse physiological processes and perhaps anchored in the nuclear signal-code of the cells, one can compare or translate this into the functions of human intelligence, dedication and initiative, in the case of the building process. Whenever one of these lacks, is blocked or misguided, things will turn sour with great certainty.

In fact, the most truly human function in the building process is that of healing, correction and adaptation. Gaps in responsibility or decision making charts can only be bridged by people who recognize the defect, and are capable and willing to correct it, including the personal risk that the taking of a decision or responsibility may imply. Or: a weak link in the communication network may shortcircuiting or circumventing the instituted communication channels. This will only happen if somebody takes it up on himself, upon his perception of the circumstances and his initiative to introduce a correction although it may exceed his assigned field of endeavour.

Every practician knows of situations where "The window was left open". The right question is not, of course, to ask: Who left it open? but: What do we do in order to have somebody close it next time. It is trivial to conclude that three things are needed for this: Firstly, people have to walk by the open window. Secondly they have to see and recognize the window that is open but should not be. And thirdly they have to take the trouble to close it.

The silly example of the window is becoming much less so if it is translated into real life situations like for instance the many formwork collapses caused by insufficient bracing. Firstly the function of "walking by the window" translates into somebody being assigned to go and look at the badly assembled falsework at the right time, namely where and when "the open window" is visible. Secondly, the person doing this must be capable of recognizing an unstable situation which may require much knowledge, imagination or work, and thirdly, he must have sufficient authority and initiative to induce appropriate corrective measures and to see them through, perhaps against resistance from other agents of the building process who are answering to a conflicting set of incentives or constraints.

Without the human input, a system is a dead mechanism with all that implies. If it could be designed to absolute perfection and if the future were absolutely predictable for the period of its function, it could be used as a concept, without human ingredients. Both conditions though are far from true even for most carefully thought-out and expensive processes such as space-travel, let alone building construction, and the human element is indispensable.

It seems therefore quite sensible to call "human error", the agent which causes things to go wrong. It is, after all, humans who design, establish and operate the building process as well as the final product, thereby planting the seed of the weed in the form of faults and imperfections. Humans also are the only element in the process which is able to detect the weeds, i.e. faults, gaps, or their consequences somewhere along the line, and root them out, i.e. eliminate them or correct the consequences in time. No mechanical or electronic system of present vintage can do this yet, and it is thought that the weeding out of faults in a process of human endeavour requires rather highly associative thinking processes and awareness which will not be accessible very soon to electronic replacements of the human mind. Consider again the notorious case of the insufficient bracing of falsework in this context: it will take an experienced engineer a certain amount of judgement to assess the situation in general, as well as to select the critical elements which he will then proceed to check in detail, establishing that the right type and size of bracing member was used and that the connections are secure, etc. A device based on electronic circuits which are all predesigned can not use "unclean" methods or shortcuts such as concentrating only on the essential points. This is only possible by extensive use of experience which is often not available in a form compatible with the rigorous requirements of electronic processing.

Again, therefore, the agent causing the error as well as the one able to eliminate it, will remain human, for the foreseeable future. On the other hand of course, systems and computing devices will hopefully become able to evaluate the error-proneness of certain well-defined situations, and perhaps, yield methods to minimize it, by strategic selection and positioning of humans in the building process, for "seeding" as well as "weeding".

5. A RESEARCH TOOL MODELLING THE BUILDING PROCESS

Research on human or gross error and its consequences will have to deal with at least four completely different types of task:

- Data on structural mishaps has been collected and must be collected more intensively in the future. This data will need to be classified and coded and stored for analysis.

- Diagnostic and formalized experience must be gained from those data, by analyzing their relation to the description of the associated building processes.

- Analysis of future or projected situations using their experience can now be performed, revealing recurring or typical relationships empirically, and through rational interpretation.

- Finally, strategies to reduce errorproneness can, hopefully, be designed to be applied to future projects, in order to reduce proneness to error.

The building process is seen as an organism, quite comparable to a living one in many respects, as it is composed of natural, living elements, and changes its composition, activities and size as time goes by. It will therefore respond to the influence of many parameters of diverse description and conceptual character (see Appendix for a tentative listing). A research tool with which to handle such diversity must therefore be adaptable to every kind of information, whether it be quantifiable or only qualitative, precise or fuzzy, relating to whichever discipline of human activity, or of perceived physical reality.

Several partial or "sub-models" can be perceived presently to illustrate capabilities which the research tool will have to offer among others in order to deal with different aspects of the problem. As the research advances, more may become evident, and more encompassing models will be conceived.

- One of the essential aspects or sub-models is, of course, the total of the physical properties of the product of the building process, i.e. the structure to be built. Its description will therefore have to be represented, at least as far as it is found to be relevant.

- Another, less mundane is the organization of the building process in terms of hierarchy, decision making, responsibility etc. The model must therefore include such functions as "organigrammes", "responsibility maps", and "decision-trees" to deal with parameters relating to the organizational side of the problem, all these concepts being little more than names of sub-models.

- Communication which is known to be at the origin of numerous cases where " things went wrong", could perhaps be visualized substituting a network of electric wiring at some points of which information (power) is being fed in or created which then flows wherever the properties of the network will let it. Connections with high resistance will block the current partially or entirely and will heat up, to indicate trouble spots. Similar to such a physical analogue which may serve for visualization of the complex problem or for discussion, other examples can be conceived to reflect other aspects of the building process.

- The introduction, perpetuation and discovery of errors for instance can be pictured as follows: A box open at the top contains a quantity of balls of different sizes and colours which represent the different deviations or errors occuring during planning, construction and use of a structure. White balls represent correct actions, color shades wrong ones. Different sizes relate to different gravity of errors, different colours to different trades/disciplines. All human individuals involved in the planning/construction/use of the structure act as passersby, putting balls into the box (acting out their tasks and hereby committing errors), or taking them out (correcting errors). They are all more or less colourblind and as history advances, balls accumulate in the box and settle to the lower layers where they are no longer visible. Large balls of course are more visible, and will therefore be recognized more easily etc... etc...

The particular mathematics of such partial models appear to be quite accessible presently and transparent enough to allow testing with real data although of course, partial models will always extend only to "partial aspects of the entire problem complex. Only their assembly into a complete system reflecting all aspects can be hoped to justly represent reality, including all cross relations of the "partial models" among each other.

The entire model would then become a combination of many partial models similar to the examples suggested above. More rigorously, it could be conceived in the form of an error-proneness function existing in the multi-dimensional space determined by the parameters of the building process, while the function itself is described by a number of parameters, e.g. the gravity of the error, or the character of the presumable consequences (collapse, deterioration, damage etc.)

A possible measure for the error-proneness would then be the expected negative value of effects assigned to errors vs the total value of production answering a particular description, for example the proportion of damage expected to "concrete high rise residential construction, if design-built under a general contract given to the low bidder disregarding experience and record of the entreprise".

Data will be fed into the model which functions as a receptacle and stores away coded descriptions of case histories. As data accumulates, certain features will become repetitive and sifting for certain properties becomes possible: e.g. "in the cases relating to punching shear failure: was it fairly common that no experienced engineer ever looked at the drawing?"

Systematic scanning for features or combination of such occurring with inordinate frequency will be performed by the computing device which will identify circumstances that have not been recognized because they were too complex, perhaps concerning a combination of parameters that were never suspected of being deleterious. In the case that no such surprises are found, their absence will be quite valuable information.

The model containing all the accumulated data, as well as all the results of surveys performed can thus become a repository of codified experience to be used to evaluate projected cases where tentative data of a construction project is compared to existing information.

Eventually it will become a design tool in the sense of optimizing projects, in terms of organization, personnel selection, reporting system, checking and supervision etc., i.e. minimizing error-proneness as a function of all these aspects (parameters).

6. DIRECTION OF RESEARCH

From the diversity of parameters it is quite clear that a research enterprise of this scope and aim must include skills and knowledge of an equally wide diversity. It will therefore have to become a truly interdisciplinary exercise with input and experience to be mustered from many fields such as:

- Logic, semantics. To start with, an important effort is needed in order to classify and clarify parameters, to eliminate duplication, overlap, undue correlation and, of course to straighten-out the terminology.

- Management. This discipline of modern science has applied itself to similar problems. The building process as a whole has formed the subject of management research although usually the objectives of that research were somewhat different, relating to immediate economy of money and time. However, methods and insight gained will certainly be very valuable for the research on errors.

- Mathematics. The codification and treatment of data, and of proposed hypotheses for parameter studies require a great deal of input from the mathematical sciences, both theoretical and applied. As the number and variety of parameters is substantial and data, on the other hand, will be comparably scarce, at least initially, the reliability of the results will be one of the major problems. It is thought that by imaginative application of mathematical methods, a great deal can be gained.

- Informatics. This discipline will be engaged for the preparation of the computer model of the building process which, at the same time, must be capable of handling the data and analytical tasks, as well as be sufficiently transparent so that it can be efficiently used by non-specialists. Black-box effects must be reduced to a minimum if the model shall become an efficient research tool.

- Civil engineering, construction. Certain aspects of the problem are definitely tied to the characteristics of the construction industry, as opposed to, say the manufacturing industry. For example the products of building industry are still essentially "one of a kind" with all this implies, compared to, say, the production of an assembly line process. It is therefore of essence that people familiar with the subtleties of building design, and construction, join the team since the experience and common sense of the practician will be an important element in data acquisition, as well as in separating relevant from unimportant features.

- Insurances, Legal implications. Many failures will pass through the insurance and legal processes in the course of their history, and the parameters this imposes on the building process, in particular through the establishment of incentives, negative or positive, are of prime importance. In some countries, the public, or in others, the insurance companies, assume functions of supervision, verification and control of construction, as opposed to construction in other countries where the public function is quite limited, or outright superficial, consisting in handing out building permits if anything at all, and of course of stepping in upon the event of injury or death, or of criminal acts. The influence of these relationships on the error-proneness of a building process is not well understood at all at this time, but neither can one reasonably exclude the existence of a correlation. Insurance companies also happen to be in possession of the greatest amount of data on construction mishaps, including the legal analysis and the final assessment, or judgement passed on every case, whether or not this was done in court.

- Sociology, psychology. It was recognized above that the personal involvement of the participants in a building process is a very important ingredient, especially when it comes to the interpretation and direction of the human activities. The actions of this "living" portion of the building process are not subject to the laws imposed by the physical circumstances and hence not predictable in the common sense of the word. In return they must be invoked to meet unforeseen conditions. The comprehension of human performance is therefore the most important element in any assessment of the problem of error and the human sciences have their essential role in the research endeavours.

- Economics. Economics very often provides important restraints on certain parameters, in particular those concerning intial cost without yielding direct return, such as expenditures for supervision, checking etc. It is hoped that the research on errors will produce measurable benefits in terms of failures and damages avoided through more judicious allocation of resources to "where it counts", i.e. economically.

- Languages. Important contributions exist in the literature in many languages: German, French, Spanish, probably Portuguese, Italian and Russian etc. Direct access to those must be readily possible, preferably by members of the research team mastering one or the other.

It must be emphasized that the research will have to start with a very serious effort in logics and semantics since, as evidenced by the list of parameters (Appendix); the complexity of the problem and the inter-relation of the parameters precludes systematic data processing at this time. This experience was gained from an attempt to compose a sensible and complete questionnaire, for the collection of data on structural failure cases. The introduction of questions relating to human parameters quickly became stuck in a semantic confusion on what means what, as well as about the classification and separation of parameters. Clear cut descriptions of such concepts as "responsibility map, communication network, management set-up" etc. are not at all ready in terms of parameters usable for data processing.

Once a definite set of parameters will be compiled, more clear cut than what is listed in the Appendix of this paper, and hopefully orthogonal, as far as possible, it will then and only then be possible to start constructing and using the model of the building process in a systematic manner, and to mobilize computer aid for sorting and searching data.

SUMMARY, CONCLUSIONS

The research endeavour envisaged and described by the present report, is indeed both very challenging and difficult. As it turns out, its successful completion will require a great amount of highly qualified work from many different sciences, "soft" and "hard" which will have to be combined in a concerted effort.

The problems of human error as the prime source of structural failure has been known to exist, as a fact of life, for a long time and traditionally, it was dealt with on a practical level by applying checking and supervision activities. These in turn had evolved mostly on the basis of common sense concepts, and of course the personal experience of the individuals participating in the building process.

Common sense is of limited reach in more complex situations, and traditional methods have not led to the elimination of human error as a deleterious agent. On the contrary, the increased complexity of building processes, in terms of organization and interrelation, tends to make them more error-prone as the traditional "master of the work" is no longer a job to be filled by one devoted and capable individual but is replaced by organisations assembling many people, none of whom can overlook the entire organism, and none of whom has an overall incentive related to the success of the job in every respect.

Recent research has shown that the classic theories of probabilistics and statistics are of very limited application when it comes to the analysis of gross error. New ways must therefore be found to deal with the problem. Based on a number of observations on the nature of the problem, it is concluded that they will have to consist in an interdisciplinary reasearch effort, using data on the description of cases of structural failure, and a model of the building process.

The anticipated result will consist of strategies to be applied in the organisation, personnel selection, scheduling etc. of building process which will eliminate situations of error-proneness and eventually, reduce losses through the minimization of the risk of failure.

APPENDIX A

PARAMETERS* TO THE PROBLEM OF "HUMAN" OR "GROSS" ERROR IN BUILDING

This is an attempt to list the parameters which are related to "error proneness" of a building process.

The parameters are classed in general categories along concepts that are self evident, and without much regard to possible correlation among them. Since it will be one of the major tasks of the research programme to disentangle the many diverse aspects and cast them as much as possible into a codeable list of clearly describable quantities, the following presentation must not be expected to be either precise or complete. A great effort in logic and semantics will be needed to produce a more sensible classification.

a. Physical and geometric properties of the product and its environment:

Size.
Weight.
Material properties including inherent properties like ductility, durability, toughness etc.
Type of structure.
Size and shapes of elements.
Connection methods: welding, bolting, gluing, prestressing, grouting etc.
Construction time.
Foundation (soil) conditions.
Geographical location.
Climate.
Seismicity.

b. Logistic properties of the product:

Degree of redundancy. (Defensive Capabilities)
Ductility/brittleness
Complexity
Proneness to progressive collapse
Repetitiveness
Novelty
Construction sequence

c. Purpose and usage:

Intended lifetime.
Origin of loads (gravity, traffic, etc.).
Character of loads (permanent, dynamic, variable, concentrated including statistical description).
Anticipated or possible changes in loads, due to change in conditions originating outside the structure (e.g. truck weights, accumulation of sand etc.) or due to changes in use.
Accidental loading.

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* Some parameters listed below may have to be expressed by more than one dimension to allow a complete description e.g. the parameter "Materials" will include indication on all materials used, with particulars about their properties.

d. Management, Organization:

Hierarchy and reporting.
Decision making.
Responsibility.
Communication.
Payment schedule and practice.
Profit/loss conditions (business incentives).
Hiring and staffing policies.
Continuity of staff.
Make-up of participants.
Unauthorized interference.

e. Institutional parameters (external to building process)

Political systems.
Social conditions.
Economy.
Labour relations.
Insurance conditions.
Civil authorities having jurisdiction.
Codes and standards, Reglementation.
Legal consequences.
Bureaucracy.
Economic constraints.

f. Human conditions for participants

Degree of capabilities relative to position.
Personal incentives - financial, social, advancement.
Education.
Knowledge.
Experience.
Initiative.
Versatility.
Intelligence
Ethics
Degree of stress.
Health.
Marital status.
Age.
Origin, cultural background.
Relationship with teammates, superiors, subordinates, substitutes, other participants.

g. Checking, control, supervision correction

Resources - financial, human.
Responsibility and authority of checking agents.
Tolerance level relative to errors and deviations.
Efficiency of correction measures.
Map of application in building process.

h. Characteristics of Errors and Consequences (Parameters to describe "Error-Proneness")

Type of Error (omission, miscalculation, lack of knowledge, distortion of information).
Frequency.
Gravity of Error.
Difficulty of Detection.
Economic consequences.
Human consequences.
Legal dimensions.
Knowledge gained (same error less likely in future etc.).

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