Tony Bryan

Second Edition

Construction Technology

Analysis and Choice

WILEY-BLACKWELL

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Preface

This book has been prepared for those at the beginning of their career studying with a view to practise in one of the professions concerned with the construction of buildings. It is written for the novice who, with study and experience, will become an expert in his or her chosen field. The more fundamental ideas developed in the text may need to be revisited as experience grows and it is, therefore, hopefully a text that can be referred to in the early years of practice and maybe beyond.

The book takes as its theme the process of choice: what the expert has to know and how the expert could think through the myriad decisions that have to be made about the design, production, maintenance and disposal of buildings. While this involves a process of analysis, the basis of which is universally applicable, the final choice is dictated by context.

The context is set by time and place, the nature of the activity to be undertaken in the building and the aspirations of its benefactor or client. The process of choice is seeking appropriate solutions in a physical and cultural context.

For a text of this nature it may seem to be dominated by words and not illustrations. The contention is that for the novice or the practising professional faced with new ideas and situations the explanation of possible solutions is required. Presenting a final working drawing may be the outcome of choice, but it is the process of analysis with its need for explanations that gives the confidence that it will perform and can be built in the context of the particular building. A picture only paints a thousand words if you already have the words to explain it.

It is hoped that the reader will find that the text tells a good story, that the development of the ideas is logical and easy to follow, but perhaps above all that it is seen as valuable in the world of practice. It is hoped that the text will be illuminating and the illustrations supportive in providing the explanations of both the analysis and the solutions suggested for choice.

The first part of the book focuses on the key areas of analysis that have to be considered to check that the proposed construction will perform (will not fail) and can be built. These two tests are seen as fundamental to the final choice. In order to carry out these analyses this book suggests that it is necessary to visualise not only the physical form of final construction, however outline or tentative, but also, equally importantly, its response to the dynamic conditions under which it has to perform. The key question is 'What if I do it like this?' The answer comes from an understanding of how it works and how it is built, this understanding coming from explanations of why things happen, drawing on knowledge from a number of other disciplines such as science and economics.

Each of the areas of analysis presented in this book is independent, and therefore each analysis has to be separate, yet all have to be satisfactory before the final choice is made. Choice is a juggling act: checking a proposal in one area of analysis may suggest changes that will affect others. Structurally sound solutions may be difficult to build or solutions that will last without maintenance too expensive as a capital investment. The final choice must satisfy all the areas of analysis.

The second and third parts of the book put analysis into practice, focusing on making the final choice. Given the approach identified in the first part of the book, with context being so important, the chapters in Parts 2 and 3 are written from the perspective of making choices for construction in the UK at the beginning of the twenty-first century. In Part 2 the focus is on housing, while Part 3 is concerned with the commercial use and scale of building. While these both take place in the same physical and cultural environments, the way buildings are commissioned and designed varies. For mass housing the choice of technical solutions is made by the developer/builder and this leads to a convergence of detailing and specification for the construction. This current common form of house construction is presented in Part 2. In commercial building there is considerably more diversity in the use and scale of the building, leading to more variety in both the mix of technologies and in detailing and specification. This greater need to consider broad options early in the design and to be clear about the potential for the technical solution is reflected in the approach developed in Part 3.

The final chapter provides a guide to the wide range of published material that is available to develop knowledge beyond this book and particularly to support the process of choice. The book itself gives no direct references. The notion of the framework for understanding developed in the book encourages the idea of seeking relevant and current information in the context of each project. It is hoped that this final chapter introduces the sources of information that will complement the approach developed in this book in order to put these ideas into practice.

This book is written with the conviction that by focusing on the process of choice the range of theory and knowledge that is useful to practice becomes explicit, making the link between knowledge and practice and between understanding and experience clear.

As study, and then practice, unfolds for each individual it is the power to reflect that develops understanding. It is hoped that the framework suggested in this book will help not just the process of choice but also the process of reflection. Readers should take from this text what understanding they can to use it to develop their own good judgement in whatever part they play in the great enterprise of construction and the development of the built environment.

Tony Bryan

Book website at www.wiley.com/go/bryanconstructiontech2e

Contains nearly 200 fully referenced, clear line drawings to download for free, as well as suggested learning activities for lecturers to incorporate into their teaching programmes.

Part 1
Analysis

1 The Framework for Understanding

This opening chapter outlines a framework to help develop an understanding of what has to be known in order to take decisions on how we should build. The framework suggests a way of going about selecting construction and identifies the knowledge that is required to make the choice. It is the framework that will be developed and used throughout the book.

Process and knowledge

This book provides examples of construction, showing how we currently build, and provides an introduction to the understanding necessary to explain how the construction works. These two types of knowledge are both vital to making decisions as to how we should create and maintain buildings in the future. This book sets this knowledge in the context of the process of making choices for the construction. In practice, a great deal of knowledge exists of the types of construction we might use and the materials and details that might be specified. There is, however, the need for any proposed construction works to answer the questions 'Will it fail?' and 'Can it be built?' Clearly it requires the answer to these two questions to be 'No, it will not fail' and 'Yes, it can be built'. These categorical no and yes answers may be difficult to give in practice. There often needs to be some analysis to develop a level of confidence with which to make the choice. The amount of analysis required determines the level of understanding and experience needed to provide the evaluation of the suggested solution before the decision is taken to put the final proposal into practice.

It is this basic ability to make a suggestion of how a building might be constructed and then to carry out an evaluation asking the questions whether it will fail and whether it can be built that is developed in this book. The evaluation points to changes in the suggestion, which after re-evaluation will lead, through a series of refinements, to the specification and details to be adopted.

This requires knowledge of what potential solutions might look like, with current practice and precedent as the major sources for an initial suggestion. It requires an understanding of what is necessary to be specified in order to describe the proposed construction in sufficient detail to carry out the evaluation. The ability to carry out the evaluation, on the other hand, is dependent on an ability to 'see' the proposal working in the dynamic systems of the physical and social conditions in which the building is to be built.

This process of choice and the way it leads to the identification of the knowledge required is shown in Figure 1.1.

It will be shown later that the process of choice is not just an analysis of the behaviour of physical performance. This evaluation of a proposal's response to the dynamic physical, chemical and biological systems of nature is vital, but building also takes place in a social and cultural context. There will be an imperative to ensure that the resources and know-how are available to manufacture and assemble the construction. This will require knowledge of the available industrial systems. Further, it will be necessary to ensure that the cost of the solution

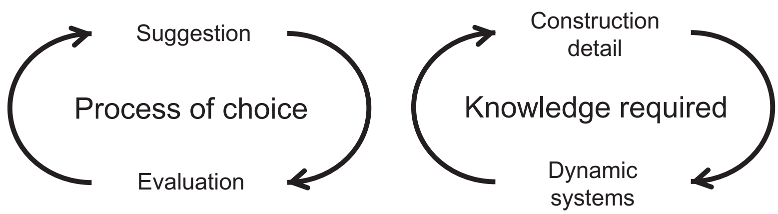

Figure 1.1 Relationship of process of choice to knowledge required.

is monitored and that its social and environmental impact is audited. These will demand an understanding of both the economic and social systems in which the building is to be created.

The initial suggestion

If the process is suggestion and evaluation, and the starting point is suggestion, it is necessary to know how we make the initial suggestion. How do we make that first best guess?

In most cases the suggestion is informed by precedents. It is necessary to have knowledge of current solutions and how they perform in practice. Something, somewhere, has been done before that gives clues as to how the new solutions might be formulated. In times where change is limited the particular circumstances will have been faced a number of times in the past and successful solutions will have evolved. The well-tried and tested solution needs only to be suggested and, with some evaluation to ensure the circumstances have not materially changed, can be immediately adopted. If the circumstances are changing, current solutions may still be the best starting point. They represent not only a sound basis in performance but also an existing base of resources and know-how to manufacture and produce the materials and details. Evaluation may modify but not fundamentally change the solution. This, over time, gives rise to a number of general forms from which specific solutions can be derived.

In some cases, perhaps where there are increasing user demands, or the structure of industrial practice is changing, then similar or related practice may have to be investigated. On the rare occasions where suggestions have to be derived from little or no existing previous work, a more fundamental understanding of the behaviour of the construction will have to be applied.

While experts approach making suggestions based on their knowledge and experience, it is, in many ways, not necessary to know much at all to make suggestions. It is the evaluation that requires the expertise. Novices or casual observers may make suggestions that may be hailed as brilliant observation, but in truth they have no way of knowing whether that particular suggestion is workable or not. It will take the expert to spot its potential and prove its worth through evaluation.

The power of the expert to spot potential is probably associated with the ability to carry out a rapid, approximate evaluation before subjecting the suggestion to more rigorous and explicit analysis.

Carrying out the evaluation

The heart of the success of the process of technological choice lies in the ability to be able to carry out an evaluation. The need to carry out a series of analytical exercises determines the knowledge required and manner of its application. It requires a level of understanding to answer the question 'What if we built the building as proposed?'

While the suggestion and the ultimate solution describe the construction in what appears to be a static detail, the evaluation of the suggested construction has to describe a dynamic system of behaviour ('Will it fail?') and a production process ('Can it be built?').

The process starts with the client's brief, the design then being devised from the requirements of those who commission the works, and as a response to the social and physical context in which the building is to be built. It is against these criteria that failure will be judged. There will be many possible ways to construct a building to achieve performance expressed in the client's brief. The criteria for choice of the technical solution come from the identification of the function of the parts and how they contribute to the function of the building as a whole.

The dynamic behaviour of the construction responding to changing conditions has to be understood, anticipating the modes of failure. Some specification of performance has to be established and then the suggestion has to be tested in the mind to assess the risk of failure within agreed design conditions.

It is easy to see technology as only the final construction, an assembly of components and materials, the building as a static object. However, making the choice of what construction should be adopted has to be rooted in an understanding of the construction as a dynamic system responding to changes in conditions and open to a failure to perform.

It is necessary to be able to visualise not only the physical construction but also its behaviour under the conditions it will have to endure in its working life. Both of these are of equal importance. If the suggestion is not visualised correctly, its behaviour under analysis may be misinterpreted. If the dynamic system of behaviour is not visualised correctly, a flawed proposal may be adopted. Visualising the building as a dynamic system will involve identifying the flows and transfers that take place both within the building and through the construction itself. These ideas are explained in Chapter 7.

Technological choice demands skills in these areas of visualising the object and the systems, and then the conceptual manipulation of the systems acting on the construction to predict behaviour and assess the risk of failure.

If the two basic questions to ask of a proposed solution are whether it will fail and whether it can be built, the criteria for choice come from an understanding not only of the potential dynamic flows and transfers when the building is in operation but also of the resources available. The performance of construction can only be realised if the resources are available to construct the building. This relies on the manufacturing and assembly possibilities but will also include the existence of design expertise and the options for maintenance and disposal. Knowledge of available techniques and know-how for production is crucial to the choice of the final construction if it is to be successful in reality as well as on paper.

As a design concept emerges, it is necessary to question what construction solutions may be used to fulfil the design requirements. It is then necessary to question whether this solution is available with current technology and resources within any environmental, cost or time requirements. The resources available make the design a reality. Technology stands between the design of the building and the management of the resources.

Choices can be made that may extend current production and design knowledge, but this must be recognised, and any costs involved in prototypes or training and the risks involved must be accepted before the final choice is made.

The design and resources available condition the choice. These two areas are shown in Figure 1.2. These are the two areas that have to be understood before any analysis can be started leading to the final choice of construction.

Physical and social context

Figure 1.2 also indicates that before any choice for a specific building can be made it is necessary to understand something of the context in which it will be constructed. There needs to be some knowledge of the conditions that exist when and where the building is to be built, possibly with some assessment of how conditions may change in the future.

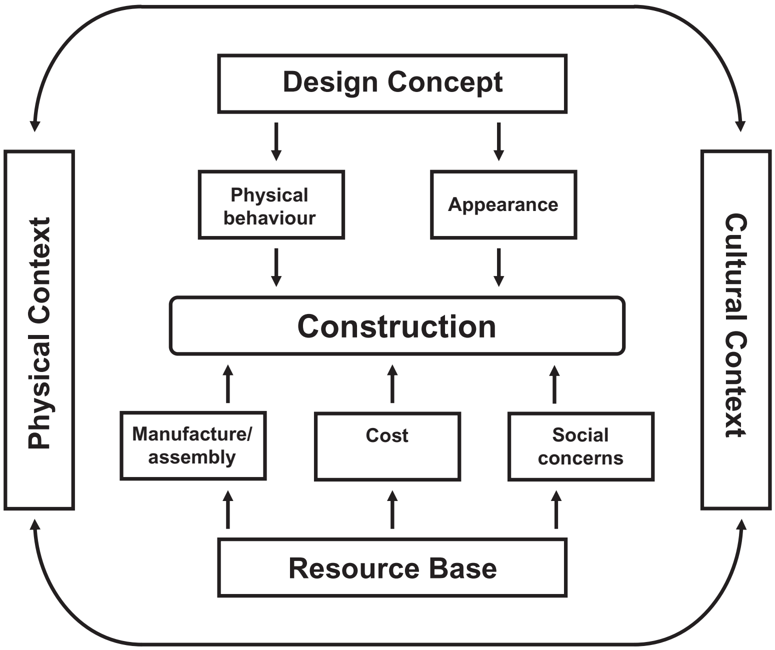

Figure 1.2 Framework of analysis.

Construction takes place within, and has an impact on, the world in which it is undertaken. Some description of this world is necessary for both technical and socio-economic analyses. The world can be represented as a series of contexts, both physical and cultural. The physical context includes nature and climate. These exert forces that act on the building; they provide the raw resources and may be adversely affected by the construction and operation of buildings. The physical context includes the surrounding development and the need for the design to respond to existing buildings and spaces.

People and their social, economic and political systems create the cultural context. It needs a response to local, national and even global needs based on beliefs and fundamental world views of the relationship between individuals and between society and the other components of the natural world.

The interaction between these two sets of contexts has been brought into focus at the beginning of the twenty-first century by the movement for sustainable development. The realisation that development cannot continue without consideration of its impact on the natural environment as well as established economic and social considerations calls for new knowledge associated with materials choice, energy use and waste disposal aspects of our chosen construction.

There are, therefore, dangers in seeing these two sets of contexts as separate. However, it is still useful to consider them as having different dynamics, as, generally, in order to resolve technical questions, it is necessary to have an understanding of the physical context, while to evaluate the chance of a solution being successfully applied requires an understanding of society, its economic and political systems.

The basis of analysis

Having identified the design concept and the resource base as providing the criteria for choice and having recognised the need to understand the physical and social context in which we build, it is possible to identify five areas of analysis as shown in Figure 1.2.

The design concept is the translation of the physical and social needs for the operation of the whole building into a scheme that identifies the function and performance of each of the parts. In order to achieve this, the design concept has to articulate both the arrangement and appearance of the spaces and the technical contribution each part of the construction will make to the creation and maintenance of the internal conditions.

Two tests indicated in Figure 1.2 have to be applied to a suggestion to see if it complies with the design concept:

- Does the *physical behaviour* of the construction provide a building fulfilling its functions to the required performance level?
- Does it provide the right attributes of *appearance*?

The test for physical behaviour involves three separate areas of analysis:

- Creating environments
- Under load
- Over time

Three tests indicated in Figure 1.2 have to be applied to a suggestion to see if it is achievable with available resources:

- Can it be produced, including *its manufacture and assembly* and the subsequent processes of maintenance and disposal, with existing skills and know-how in a reasonable time and at the required quality?
- Are the resources available at reasonable *cost*?
- Will it be compatible with the *social concerns* that currently exist?

These resources are both natural (from the environment) and social, so both aspects have to be part of the evaluation. It is only possible to use resources that nature has provided. However, the level of economic development in a society will provide the capacity to process materials, develop the skills and machinery to work them, the intellectual capacity to undertake design and the provision of capital to invest in the enterprise of the construction itself. Both the technical properties of materials and the existence of the knowledge to exploit them plus any environmental impact of their use must be analysed in evaluating a suggested form of construction.

These seven areas of analysis (physical behaviour being three) that have to be undertaken are, by and large, unrelated to each other and each needs its own tools of analysis and knowledge base to be successfully applied. Carrying out one analysis may indicate the need for a change in the suggestion, but the change that is chosen may make the analysis of a previous aspect invalid. It is not until all the relevant areas of analysis are shown to be satisfactory that the suggestions can be adopted as the solution.

These seven areas of analysis have potentially to be undertaken for all aspects of the construction, from the overall structural system to the finest detail such as the screw that fixes the final fitting to a wall. The work in this is clearly overwhelming if it has to be carried out for every building that is constructed. Current practice can inform much of the process of choice. One of the most important decisions that experts take is, of all the thousands of choices that have to be made to fully specify the construction, which of the areas of analysis for which parts of the building are significant. Where, if analysis is not thought through, is the greatest risk of failure?

It is not clear how experts make this judgement. One possible explanation is that while looking at a suggestion they make many rapid checks against the seven criteria. From their knowledge and experience they take a view on what is well within failure limits and where the risks of failure are higher.

Knowledge needed for choice

It is now possible to start to identify the knowledge that is required and the areas of understanding that have to be developed in order to carry out a full evaluation. Although used in various combinations in the different areas of analysis, it is possible to put forward a tentative list of types of knowledge that will be required:

- Setting the performance levels as the criteria against which the evaluation will be made.
- Defining the conditions under which performance has to be achieved.
- Determining the fundamental behaviour of the construction that would lead to failure to meet performance requirements.
- Identifying the materials' properties that will govern the behaviour that could lead to failure.
- Thinking through the behaviour of the particular combination of materials and details under the conditions envisaged.
- Identifying the process of manufacture and assembly together with the resources required to produce the building within quality, time, cost and safety limits.
- The cost in economic, social and environmental terms of using a particular form of construction.

The process of evaluation requires the building to be conceptualised in a number of ways. While the final building will be seen as a physical construction, 'bricks and mortar', it is necessary to perceive the building in a number of other ways when carrying out the evaluation. Initially, the construction has to be seen as fulfilling a set of functions with associated performance levels. For evaluation, the building has to be viewed as a series of physical systems responding dynamically to changing conditions. The building then has to be seen as a series of production operations with the resources required for the realisation of the design. All these will have economic, environmental and social implications that have to be understood. When all these can be mastered, choices can be made associated with an assessment of risk and with some confidence of a successful building.

Summary

1. The process of choice is one of suggestions and evaluation that requires knowledge of the physical construction and the dynamic systems in which it will be built and will operate.
2. How a suggestion is generated, and the extent to which a formal evaluation has to be undertaken, depends on the scale and nature of any changes from current practice required by either the design or the resources available.
3. When there is a changing demand for buildings and rapidly developing technical knowledge, the role of experience changes from predominantly reproducing known solutions to the integration of experience into a process of analysis to explore the possibilities of failure in the modified or new solutions before they are built.
4. The design and the resource availability define the criteria for the evaluation. This has to be set within a physical and cultural context.
5. The suggestion will probably be based on precedent and this leads to general forms from which specific solutions can be derived.
6. The evaluation needs to be carried out through seven areas of analysis: appearance, behaviour creating environments, behaviour under load, behaviour over time, manufacture and assembly, cost and social concerns.
7. This will involve constant reference to both production and design. The concern is for what will not fail and can be built.

2 Building Purpose and Performance

Technology is used to mediate between the world as it is and the world as we want it. This chapter expands this idea, focusing on the users and their activities, introducing the functions expected of the building and how these have to be translated into a process of choice for the construction of each part.

Activities, space and construction

Buildings are often characterised by their overall purpose or function – house, factory, hospital, prison, etc. – and are often immediately recognisable although their architecture may vary. To understand the form of the building, it is necessary to understand the day-to-day activities that make up the function for which the building is commissioned. The construction will have to play its part in ensuring the well-being of these activities. The notion of well-being is normally associated with the people who use the spaces, but the building will have to protect the equipment being used and the storage of items associated with the activities. Well-being of people also needs to include the requirements of the owner and the wider public, as buildings are social institutions and create the surrounding spaces.

The majority of spaces in buildings have to accommodate people and consideration of their well-being becomes a dominant aspect of the performance of the construction. In some cases, such as the rooms for the early computers and specialist storage areas such as vaults and cold stores, the equipment housed in the building or the storage conditions dominate the requirements. Designing for the well-being of people is essentially concerned with health, safety and comfort. Health should be understood as meaning both physical and mental health, both being a function of physical and social conditions created by the building.

The owner may see a purpose beyond the simple support of activities, to include image and status. The surroundings in which the activities are undertaken have social significance and must form a feature of the design.

Each society over time evolves common building forms for each purpose type that become recognisable within that society because of their size, arrangements of internal spaces and social statement. With this emergence of building form there is a need to develop appropriate construction solutions. This process is dealt with in more detail in Chapter 3, but first this chapter explores the complex range of performance issues. These will be established predominantly by the users' activities, although later by the owner and then by government in the form of legislation on behalf of society as a whole.

Introduction to performance requirements

In order to explore the range of performance issues it is useful to engage in a mind experiment. The situation to be imagined is one where civilisation as we know it does not exist and the task is to provide shelter. The scenario is one of few resources of materials, labour or knowledge. There is also little development of an economic system, so the whole design and production process has to be undertaken by the users. The mind experiment starts by asking which performance the user of the building would seek to satisfy first. The experiment can then be extended through time, assuming increasing resources and socialisation, introducing additional requirements that would add value and utility and improve well-being.

By undertaking this mind experiment it will be possible to introduce the needs of the user and hence the functions that he or she will require the building to fulfil. As the user is also, at least initially, the designer and builder of the shelter, he/she must decide on the construction. The experiment will, therefore, also start to introduce the ideas and knowledge that will be needed to make decisions on the construction of the building itself. All the issues and factors introduced here are still relevant today.

In the beginning

Given no immediate risk from attack, we can speculate that people would organise their technological endeavour in the following way. Thought would have to be given to the range of activities of everyday life that should be housed in the shelter. Initially this is likely to be very few, perhaps only sleeping, with most activity being undertaken outside depending on the prevailing climate. This will provide a definition of size and any division of the internal space that needs to be made. It would be immediately recognised that these requirements for size and shape would be limited by the possible construction available. Some decision would have to be made as to how much effort should go into developing construction to match aspirations or use existing resources to satisfy immediate needs.

The priority in terms of establishing functions for the building fabric would be to remain dry, a condition fundamental to the health and comfort of people and the storage of many natural products. This would be accompanied by the requirement to be warm, but it is possible that this will initially be achieved in combination with other technologies. These would include clothing and the use of fire, which at this stage may or may not be associated with the construction of the shelter.

As soon as any construction is contemplated the builder is immediately faced with achieving a stable structure and making some judgement on how long it may last. Although buildings may be erected for environmental control, their very existence demands considerations of stability and reliability if they are to be deemed satisfactory by the user. This will require the identification of possible modes of failure. At this early stage this would include how the construction might leak or fall down. This understanding of the ways in which performance may be lost becomes crucial to directing effort to significant aspects of the solution. This would also lead to some questioning of what maintenance may be necessary and what parts may have to be renewed to continue the performance until the construction had to be abandoned or demolished to make way for a new building.

It would also become necessary to have some knowledge of the environmental conditions in which the construction has to maintain performance. This knowledge would be required to consider not only the environmental control but also the stability and reliability. These three become the key physical performance issues. External climatic conditions such as frequency and volume of rainfall will need to be assessed for the weatherproofing function. Damaging wind speeds and direction would need to be assessed for stability. It would, however, soon become clear that wind is a major factor in weatherproofing. Some of the most arduous weatherproofing conditions come with wind-driven rain. It is not possible to say what aspect of the environment needs to be known to assess durability until some choice of the basic materials is made. Specific decay agents in the environment degrade different materials. Linking materials to their generators of decay is just one more question that has to be answered in the quest for knowledge to make sensible choices for the construction.

This assessment of external climate would soon reveal that often the more extreme conditions of open land are ameliorated by local natural features, that exposure can be modified by the position and orientation of the building which will limit the demands on the construction and/or give better internal conditions.

The next steps

As the number of activities carried out in the building increases, the provision of good air may be the next priority for improvement of the construction. This is probably the next requirement for health and comfort after dryness and warmth.

Seeking a solution that would improve the quality of the air would probably involve ventilation since there is an abundance of good air outside. It would have to be recognised that the air outside may also be cold and that this will make the requirement for warmth more difficult to achieve. This may mean that a solution for good air may only be possible when air temperatures outside are sufficiently high or air quality inside is particularly poor. Assuming that the active technologies of building services are not available, modification would be necessary in the existing construction. It would be necessary to use natural ventilation driven by wind pressures around the building. Openings would have to be introduced to ensure the exchange of air. Their position and size would have to be considered. It would be possible to introduce a level of control by providing shutters. The openings could eventually be as sophisticated as chimneys, but history tells us that these often come much later.

It is important to note that the containment of the bad air is a direct result of employing construction to remain dry and warm. The air outside the building is almost certainly good. This realisation that the construction itself can create undesirable conditions should not go unnoticed. Changes introduced to fulfil new performance demands may change conditions that have always been satisfactory. This happened towards the end of the twentieth century when a requirement for energy saving was satisfied by the introduction of insulation. Under some environmental conditions this led to condensation that has a deleterious effect on the basic requirement of keeping dry. This led to health problems for the users of the buildings.

The introduction of new performance requirements may also introduce failures in the construction that have previously not occurred. This happened in the condensation example, where dampness caused not only health problems but also a deterioration of the construction materials themselves. In this mind experiment it is possible to speculate on a similar problem with the improvement in internal air quality. Given the lack of social organisation to produce more processed materials, the construction would almost certainly be made of relatively unmodified organic materials. In this case it might be speculated that if the poor air had a large component of smoke it would have permeated the construction. This would have effectively fumigated the organic materials and kept infestations or decay-promoting fungi and insects at bay. Improving internal air quality may change the conditions within the construction itself. This may allow significant numbers of some of the natural agents of decay to thrive, thereby reducing the life of the construction.

More physical requirements

This mind experiment continues on the assumption that no major threat to security arises. This would inevitably lead to a diversion of resources and may change the priorities of individuals or society in seeking improvements in their buildings, although it may also lead to new types of buildings, such as defensive works.

Given peaceful social development, the next priority may be difficult to identify. It may be that the infestation of insects and small animals that will be attracted to the improved internal environment becomes a problem. It may be that in the harsh realities of life, and in the absence of any realisation of the health risks, these infestations would be tolerated. Measures to eliminate the larger animals, if not already considered as a danger, may now become important. At some time, however, infestation control would have to be included in the list of functions required of the construction to improve well-being. This is part of the more general requirement to keep the enclosed space clean. Internal surfaces that are dust-free, smooth and wipeable become desirable attributes where cleanliness becomes important to the health and comfort of the user.

Having gained good clear air, more activities could be carried on indoors. It is, therefore, possible to imagine an increasing need for light to improve comfort levels and further extend the range of activities in the building. The choice is between natural and artificial means of lighting. Natural would involve openings, while artificial would only demand a safe place to support what would almost certainly be an independent light source. Although independent of the building, it would have an influence on it. Perhaps the major influence it would have is in the increased risk from fire. While it may not be possible to improve the fire resistance of the whole building at this time, it would be sensible to employ non-combustible materials at least where the light source is to be mounted.

Here we see the increased use of technologies independent of the building, seen by the user as an asset to the well-being of the activities, influencing the required functions of the construction itself.

Another requirement is for some measure of noise control. This would, of course, only become a concern if the external level of noise were somehow interfering with the overall sense of well-being. It may become a problem when the building has separate rooms for specific activities. Noise from one activity may well be incompatible with the conditions necessary for another. Noise is a particular problem of civilisation, and especially for those societies that have advanced technologies. It also seems that it has a cultural basis in attitudes towards individual rights, privacy and intrusion.

The technical considerations become more complex

It is useful to view the need to consider noise performance from a different perspective. It may be that there is a need to modify the sound between outside and inside, yet the construction used for the other requirements already has sufficient, if not excess, ability to perform as a sound barrier. With low performance expectations the final form of construction is dictated by only a few of the functional requirements. As more functions are identified and the level of the required performance increases it becomes difficult to provide simple construction solutions. Composite solutions are necessary with different materials to satisfy different functions at the levels of performance that are required.

The analysis of exactly how each part of the construction is interacting in providing the overall function becomes more difficult. The danger comes when changes are suggested. It is necessary to ensure that the change does not make a previously satisfactory performance critical so that the construction fails to perform, in an unexpected way. The trend towards lighter partitioning in housing has, by reducing the weight and changing natural vibration frequencies, reduced the sound transmission resistance. In the past this was normally more than satisfactory when partitions were thicker or made of denser material. The lighter, cheaper solution may become critical in some situations where the soundproofing performance of the heavier solution had always been taken for granted.

The need for composite construction leads to the search for materials with properties matched to the specific functions. Processing or manufacture of materials allows these properties to be more accurately achieved. This not only changes the ability to gain performance but also influences the production resources required.

Materials and manufacturing methods may also be changed to provide more economic buildings. The innovation may not be driven by performance but in order to seek production and cost gains. This may lead to performance failure in previously satisfactory solutions. Those responsible for the choice of construction must re-evaluate the possible performance failures if construction is changed for production or cost advantages.

Taking storage and equipment into account

The environmental requirements that have been introduced are those necessary to maintain the well-being of the people who use the building. These can be summarised as:

- Dryness
- Warmth
- Cleanliness
- Light
- Quiet

Observations of this list will identify that, with only slight modifications (e.g. warmth needs to be more generally interpreted as temperature control), it could equally well be applied to maintaining the well-being of the equipment and stored items. The required internal conditions for storage and equipment may be different, even hostile to life as in the case of cold storage. They will still demand the same type of functions of the construction. There would, however, be changes in performance level due to the change in specification for the internal environment, even though the external condition may be the same. In the example of cold storage, levels of insulation would be different.

More significantly, the equipment and stored items, as well as the living occupants, will contribute to the internal environment with noise, smell, heat, fumes, etc. It may be that the construction is called on to moderate these effects by isolating storage from living areas by partitions. Independent technologies in the same room such as cooling of food may be applied using ideas such as evaporating water from a porous pot or a refrigerator. However, independent technologies may influence internal conditions. In the example of cooling food the porous pot releases vapour and the refrigerator releases heat.

The dynamics of these changes in the internal environment due to occupants and independent technologies in the building must become part of the analysis. Sealing up a building to reduce heat loss through air changes can lead to a build-up of vapour (if only from people breathing), which makes condensation more likely.

Although the list of environmental requirements generated for people will cover most circumstances associated with the equipment and storage in the building, it may in some situations be incomplete. Some modern equipment has environmental operating requirements, such as the need for anti-static precautions, that may not currently be considered necessary for the well-being of people. What has to be achieved is a balanced solution to ensure the well-being of both the participants and the processes associated with the activities for which the building is required.

What should be considered tolerable?

Setting performance levels involves considering what is tolerable. What should be considered as normal limits to be maintained in the internal conditions? What external conditions should be allowed for in the design? These questions have to be answered in terms of risk and consequences. Extremes that happen rarely but have serious consequences to the well-being of the activity or even threaten life and property may well be taken into account. The more frequent events, even with lesser consequences, are also more likely to be taken into account. This is not independent of the economic resources available and social attitudes. In many parts of the world, earthquakes will occur, but the construction to minimise the risk to life is seen as increasing costs beyond that to be extended to all sections of society. Similar circumstances have existed in the past with fire and building. Increasing wealth, effectively distributed in society, will affect what is considered tolerable, reflecting more demanding performance expectations.

Generally, wide limits would be accepted for solutions at the beginning of our mind experiment, but as societies develop they seek to extend the range and level of demands. This often includes a requirement for a greater level of control as it defines a narrower band within which performance is deemed satisfactory. These trends place more demands on the solutions and failure is more likely.

Some extremes that happen rarely have to be considered if they have serious consequences. One risk that comes from the internal activity that generates extreme conditions has already been raised. It is the issue of fire within the building. At the beginning of the mind experiment, while escape for people would be required, it is unlikely that there would be any expectation on the part of the user that any of the building would remain after a fire. Although fire is now rare in modern buildings, its consequences are such, particularly in risk to life, that it is currently deemed necessary for the construction to continue to maintain a selected range of performances both during and after the fire. This would almost certainly include stability, although insurance requirements may extend the performance range.

External climatic extremes such as wind, flood, lightning and even earthquake may be considered. Design for flood may be sensible if the building is sited by water, for lightning if a tall building and for earthquake if the building is in an unstable region of the world.

New threats created by increasing sophistication of solutions are now emerging. Draught-free homes created to conserve heat may suffer from a build-up of radon gas if built in an area of the country where it occurs naturally in the rocks below the building. The chemical contaminants in the soil on sites used for redundant industries threaten both the occupants and the fabric of the building itself.

Introducing social requirements

Having established the requirements for health and physical comfort, it is now necessary to consider the social aspects. In reality the consideration of performance for more social aspects does not come only when physical requirements have been fully satisfied. Human endeavour very quickly becomes a social activity and there grows a need for social organisation, establishing cultural norms, provision for leadership and political activities and an economic system for the exchange of goods and services. Buildings play their part in this process not only to house the activities but also in that they reflect, affirm and even become instruments for change as the cultural and economic order develops.

As well as the issues of status and image, to be discussed later in this chapter, two other functions associated with well-being arise when society starts to develop. These are the requirements for security and privacy. They are mainly associated with mental health, although the security risk, if it becomes a reality, may involve physical danger. The point at which people would take these functions into account would be dependent on the nature of the society that develops. They are not as predictable as the physical needs and may well have to be addressed before the desired level of physical comfort and safety is achieved.

Security requirements will be dependent on the existence of a perceived threat. If the risks are seen as sufficient, technological ingenuity, time and resources will be devoted to combating the threat if social devices such as the rule of law or treaties cannot be achieved. Threats come from both inside and outside a society, each of which pose different challenges to the technological skills of the builder. In the extreme, in buildings such as bunkers, the security threat dominates the design as the technology of survival becomes pitted against the technology of destruction.

The requirement of privacy is much more rooted in the cultural attitudes to community. It is cultural interpretations of what activities should be shared and those that should be carried out in private that dictate the need to introduce this performance into buildings. Performance levels of privacy can be identified associated with the senses, visual and aural being the two main requirements of the building influencing both the external envelope and normally demanding some division of internal space.

The functions of the building that have a social origin often translate into aspects of physical performance already introduced. Security makes structural demands on the fabric. Privacy determines many of the sound transmission requirements of construction.

Influence of production resources

As more functions are included and more materials are introduced, production resources and know-how have to develop. The relationship between the need for a building and the availability of the materials, skill and tools to produce it is always a determining factor in the choice of the construction. Access to production knowledge and expertise limits the pace of development of new solutions to achieve new performance. However, developments in materials and production can also suggest different ways of achieving similar performance.

This mind experiment has taken the perspective of the purpose of the building and requirements of the user. It is easy to forget that the means of realising that performance may need as much thought and ingenuity as the design and detailing of the fabric and structure of the building. In many old buildings it is easy to see how they work but often difficult to see how they might have been built without appreciating the tools and skills available at the time. In many innovative buildings, detailing is often determined as much by manufacturing or erection procedures as it is by satisfying performance. The availability of manufacturing and assembly resources also determines the cost. The need to develop production procedure affects the time to construct and risk associated with a particular solution. All these contribute to the final quality of the building and its success judged by performance.

Considering cost and value

Throughout this mind experiment the question of cost and value will have to be considered. Buildings are usually costed in terms of money, but there are also considerations of cost to the environment and on the impact they may have on the society itself. The resources available to any society are limited and decisions have to be made as to how these should be allocated. As part of the culture these are the political decisions involving both the vision of the type of society that should emerge and the preferred methods of achieving it. It is from this cultural process that demand is initiated, the cost of resources determined and value assigned.

Buildings will only be commissioned when the cost of a building that performs to an adequate standard is considered good value. If the costs are too great, decisions have to be taken on eliminating functions, reducing performance or changing production methods. These changes have to ensure that the building is still considered as value for money. Assigning this cost requires that at least a broad outline of both the construction and the production methods is known. At some point in the process the decision to proceed to full design and production based on estimated cost has to be made. For buildings that can be produced using well-developed current forms of construction this decision can be made very early with some certainty. For a project where there are few precedents, possible solutions may have to be investigated before cost can be established with sufficient certainty to take the decision to proceed. It is, however, always a requirement to set cost limits as early as possible and then develop the final solution with these costs in mind.

Building for status and image

Status and image will at some time in the development of society start to influence the requirements of the building. This may be reflected in the size of the space provided over and above that strictly required for the physical satisfaction of the activity itself. It may be associated with the quality of the materials used being acknowledged as expensive. These expensive materials must have the ability to perform their physical tasks without failure, but they could have been replaced by a less expensive alternative. These requirements are often then overlaid with issues of art and fashion and symbolism. The influence of these should not be underestimated, but a full discussion of their nature and form is inappropriate in this text.

The pressures of status and image are not just related to statements of wealth and position. We all need to make statements and feel comfortable about our place in society related to the prevailing cultural norms. It has to be recognised that these cultural norms can be highly regionalised, being associated with tribes or nations, although improved communication seems to reduce this variability. We all care about what our buildings look like and the environment they create. Using and being associated with buildings that match the psychological demands of the activities carried out in the building is very important to our mental well-being.

These issues become associated with aesthetics, the visual and deeper, even spiritual, quality of beauty of both natural and manufactured articles. These are the aspects of the world that satisfy our feelings rather than our physical needs. Buildings intrude into the rural landscape and create the cityscape. Their shape, form, colour and ornamentation have a significant impact on our lives.

Control from society and legislation

All social groups have cultural norms of behaviour that limit the actions of individuals and impose sanctions for transgressions. This eventually has to be formalised into legislation, some of which will start to impinge on the choices that may be made for construction. Direct legislation is normally associated with public health, limiting the use of scarce resources or the position and appearance of whole buildings. Once manufacture and assembly start, there are laws associated with the health and safety of operatives and people in the surrounding area.

All these will have to be acknowledged and satisfied in the final choice. If the choice of construction is made in the sprit of responsibility within the cultural norms, it should not dominate the solutions chosen. Legislation is for the protection of those who use the buildings and should, therefore, be easy to accommodate into a process whose objectives include satisfying social and individual needs.

In reality the law on these matters can be slow to change and may be drafted such that its interpretation becomes a matter of opinion. These factors can spur or inhibit technological change, but it is clear that in an advanced society those responsible for the choice of construction have to be aware of the law and its interpretation.

There is much legislation that will indirectly influence the choice of construction, although predicting and understanding the links are more difficult. Contracts become necessary between the organisations that undertake different parts of the building process. This legislation affects decisions on the construction and what risks they carry. The knowledge and experience that the organisation has then influence the choices made for the construction of the building.

Clients, users and change of purpose

Another complication that arises as society develops is that individuals who become the owner/occupiers commission fewer buildings. It is now possible for those who commission the work to be an investment company who pass on the task of operating the building to another company for use by yet another group of people. This does not nullify the idea that satisfying the needs of the user should govern the performance of the construction solutions. It is the provision of space that ensures that the desired activities can be carried out efficiently and effectively by the user that gives value and utility to a building. Those who commission the building may have objectives such as investment, but these will generally only succeed if the purpose of the building and its performance are satisfactory.

Even when relatively simple relationships between client and initial occupation exist, the purpose of the building is likely to change with time. These can be quite dramatic changes such as churches to flats, but most are much more subtle. Changing practices in medicine have made many old hospital designs inefficient and the general electronic information revolution has changed the basic activities carried out in many offices. Increasingly the operators of buildings (as opposed to the users) see the building as part of the business's efficiency. This gives different value to maintenance, alterations and refurbishment and makes the building a more integrated part of the facilities as a whole. This leads to the questions about the whole life costs. More expensive initial options may be better value over the life of the building, reducing operating costs and increasing efficiency and well-being.

Environmental impact and sustainability

This long-term view of the building leads to wider questions about environmental impact. Construction has always had a local impact on the environment; it takes resources, changes ecosystems, consumes energy and creates waste. The society in both our mind experiment and now in reality has grown more prosperous; infrastructures have improved, allowing the growth of manufacturing and materials processing to serve an expanding population with ever higher performance expectations. The environmental impact of technologies chosen for individual buildings can now contribute to global consequences.

This demands yet more analysis, with new knowledge required in order to make choices about the technology we employ for our buildings. It will lead to different solutions being favoured, innovation and risk. The story continues.

Summary

1. The purpose of the building is to support the activity to be carried out in the building using both physical and social criteria.
2. Both physical and social functions of the building lead to physical performance requirements covering environmental, structural and reliability aspects of the construction. These requirements lead to performance expectations and hence definitions of failure.
3. Choice of construction can only be made in the knowledge of the environments in which the construction operates and an understanding of the mechanisms or actions that lead to failure.
4. The other factors to be considered in making the choice of construction include production resources and know-how, cost, legislation and the need to consider the whole life of the building and its environmental impact.

3 Common Forms – Specific Solutions

This section develops the idea that in any society there is a recognisable set of common building forms. These common forms will be drawn from a range of generic types that are then worked into various specific solutions. The generic type and constructed form are two distinct ways of identifying the construction that is adopted for a building. The conceptual generic type is characterised by its arrangements of components and action in achieving performance. The physical constructed solution has defined materials, size and shape of components, joints and fixings. This construction solution becomes specific to an individual building, although the building may be repeated many times and the detail may work in many buildings.

General and constructed forms

In any society at any time there is a pattern of needs that supports a recognisable series of common building forms. For each of these building forms there will be an interrelated set of construction solutions to cope with the size of the building and the resources affordable for each. Construction solutions are derived from a limited set of generic types. Technological choice often starts with the selection of an appropriate general form that is then developed into a detailed construction solution for a specific building.

The ability to describe a building in these two forms, the general form and constructed form, at the early concept stage in the design of a building is most important. It should be the big idea from which the individual details can be developed so they work together to ensure the performance of the building as a whole.

The emergence of general building forms

It appears that the prime determinant of the construction of a building is related to space. The users' demands will translate fundamentally into spaces and their size and interrelationships will suggest the scale and shape of the building. At the domestic scale small cellular spaces lock together, while many commercial or public buildings require more voluminous spaces, often with smaller associated spaces such as toilets, to form the building as a working unit.

Construction solutions are directly related to this demand for space. Most significantly it influences the structure, but these choices have inevitable consequences on the solutions available for the construction of the enclosure and other elements of the building.

Currently there is a wide range of spatial requirements both on plan and in the height required that leads to the use of a range of structural forms. Three general groups of structural form can be identified:

- Loadbearing walls
- Skeletal frames
- Long-span roofs

Each of these will create a range of building forms, some examples of which are shown in Figure 3.1. Each building form will be made up of a combination of a range of structural

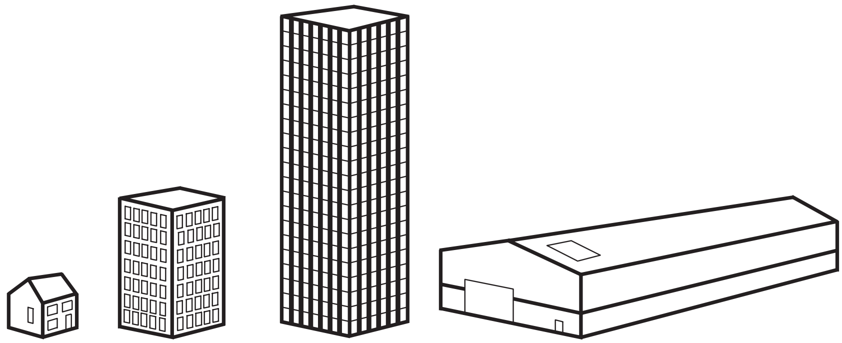

Figure 3.1 Typical form associated with types of structure.

elements. An example of a generic structural element is the beam. With its structural action in bending it appears in cellular loadbearing construction as joists for the floor and a lintel over an opening, in skeletal frames as a main structural member and in the long-span roof in a portal frame. This generic type has been adapted for specific solutions using different materials to achieve the required characteristics: great strength, small deflections, small section size, low weight, good looks, low cost, fast erection. Each of these characteristics will have a greater or lesser significance in a specific building. In a house the joist will most likely be timber; in the skeletal frame the beam will generally be steel or reinforced concrete. The portal frame is most likely to be made from steel, but for a building of the right use, scale and size it could be made from reinforced concrete or even from timber in a laminated form.

While the ability to enclose the space is the primary determinant of the generic form, design and resource conditions will lead to a dominant economic detailed solution. This leads to two ways of thinking about a building, each having it own vocabulary to describe the solution. Early in the selection of the construction it is helpful to think about the elements of the building in generic terms. This can then be developed into a full description of the constructed form, including specification of materials, joints and fixings.

Generic elemental – domestic, loadbearing walls

One widespread use for the loadbearing wall form is the house. Described in their elemental form, houses in the UK at the beginning of the twenty-first century employ a semi-permeable (cavity) construction for all external walls to provide (with internal cell walls) a stable dry box. This box will be roofed with a tiled covering supported on a trussed rafter structure taking the loads directly to the external walls. This means that any internal loadbearing walls need not extend to roof level. Suspended floors will be joisted, often taking advantage of internal walls to limit spans, making some ground-floor partitions loadbearing. Ground floors may be ground supported or suspended floors depending on the site and ground conditions. Foundations are most likely to be strip footings unless the ground conditions are very poor. This form is shown in Figure 3.2.

Many houses built in the first half of the twentieth century and still in use were not constructed like this. Many have solid permeable walls and have roofs made from individual structural members (rafters, purlins, struts and hangers) which, when acting as a whole, require internal wall support. Later in the twentieth century the width of terraced houses reduced and cross wall construction, where only walls