TECHNOLOGICAL FLEXIBILITY

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Abstract

A house, the product of the building industry, has to be a very large, durable and if possible artistically pleasing, one-off creation. The time it takes to make the product is long and the operating space available to those building it is small.

Permanently sited industry makes far smaller, mass-produced products with a shorter life. Moreover the high quality exterior is not combined with satisfaction of the demand for individuality. At the same time, the desired level of investment efficiency means that the productivity of the building industry must equal that of automated production facilities.

The means of resolving the problem are flexible production systems. The adaptability and internal flexibility of these allow variable products to be made. Utilization of the advantages of a flexible system is assisted by developing open systems (or part-systems) for design.

A multipurpose production set-up requires a high level of general and specialized expertise. The requirements go beyond the professional knowledge used so far to include the use of up-to-date machinery and information handling.

But experience with earlier developments teaches us that oversized developments requiring too much effort must be avoided. Harmonization of the tasks and the means for accomplishing them must begin at the stage when the objectives are first being formulated.

Introduction

Building technology is by nature flexible, and mass production has never really been possible for the building industry. Some parts of buildings, mostly those which are concealed, can be factory-made, but those decisive to the appearance of the building cannot. A building is an extremely costly amenity expected to be resistant to both physical and moral obsolescence. It is the prime and most conspicuous hallmark of its architect, and so it has to reflect his personality. Although buildings by Mies van der Rohe are designed in terms of industrialized construction, they are far from uniform.

The building industry's problems arise from the need to achieve the same level of efficiency as other industries do. If we take the individual, artistic character of architecture as the standard, we shall end up building magnificent cathedrals again and living in houses without modern conveniences. That is all the strength of society, in mass terms, could run to. If we take attainment of other industries, level of efficiency as the single goal, we shall soon end up living in phalansteries. I do not think anybody would want that.

Fundamental changes in production have followed the oil crises. Production cannot grow continuously because of the limitation of the market. Hitherto the expected service life curve of a product has been the basis for deciding capital investment. Should the forecast prove inaccurate, the new product has also had to bear the losses on the previous product. While production continually expands, this appears to be a possible course, but after a time, since competitors are also producing, a glut of goods emerges that makes the process impossible to sustain. This is what happened at the time of the crisis.

New systems with the same efficiency but a greater sensitivity to fast changes in requirements have had to be introduced into industrial production. Whereupon the production method ceases to be directly tied to the product, and technology becomes more stable than the product. This is just what the case has always been in the building industry. Our training has prepared us to acknowledge only the character of the product, the house, or the hospital, or only its urban, agricultural or industrial character, since buildings generally accommodate more than a single function. Depending on the choice of site, the preparatory measures and methods differ for downtown, industrial or agricultural buildings.

The peculiarity of building is that production equipment is mobile and the product stationary. Starting out from this fundamental principle, let us consider what methods, inside and outside the system, we have available for making technologies flexible.

Design flexibility

Plans for implementing a project can be divided into those that are technical, technological, organizational and financial. Let us first look at the technical arsenal available at the planning stage and at the scope it offers. The builder would have maximum leeway if the building were designed out of uniform units. But to choose a multipurpose unit of this kind would preclude the use of special materials and executions for specific purposes. These special user requirements can only be met through sitework and one-off assembly. A product made of uniform units has a low level of functional utility. The more functional the product is, the more specific and less flexible it becomes. Brick used to be suitable for both walls and vaults, but the structure was developed with this single type of unit on the site. The demands of the industry are different today, but the development goal may, for instance, be to produce, by aligning a single kind of unit, a horizontal load-bearing structure of any span desired. One good way of doing so would be to combine prefabrication with on-site construction. For instance, auxiliary units could be added to fundamental units on the site.

A system relying on a single type of unit is an extreme example, but in practice it is possible for complete system to consist of just three or four types of unit, particularly because studies of building systems with an extremely high number of units (350—400 different kinds) show that only one tenth to one fifth of the system at most is actually applied. Only 3 to 4% of the full range, i. e. 9—15 units are essential. Conscious design to this end can reduce this number to 3 or 4 units.

If one creates building systems that are open-ended from the point of view of systems analysis, the flexibility of the whole, complex entity increases. In other words, if a building system succeeds in integrating closed but adaptable subsystems, its flexibility is increased.

One subsystem has to fit into other subsystems, while remaining self-contained. In the case of a partition wall, every structure pertaining to it — doors, electrical equipment, finishes, etc. — have to fit in with it, while the partition has to fit in with the other subsystems — the load-bearing structure, suspended ceiling, etc. A suspended ceiling has to accommodate technically to any structural subsystem while retaining a varied appearance. In other words it must couple its varied appearance with technical uniformity. The load-bearing frame and joints are uniform irrespective of the appearance of the components. The same principle may underlie the design of other structures as well.

One might object that since structural dimensions vary according to the prevailing conditions, the structure itself is not the same when adapted to a different purpose. That is true if the adaptability has not been designed in. If joints of the same type have different structural dimensions but the same information requirement, fittings and know-how, they will still be no different from the previous ones. Such a system may have the drawback of requiring large stocks to be kept. But the building industry works to order, and stocks can be minimized by consciously restricting the range of units and systematizing the meeting of the orders.

Identical technology and an invariable type of structure, coupled with a mix of standard and tailor-made parts, will maintain its efficiency even in face of frequent changes and the individual demands of users. Despite frequent or even continual changes a constant information structure and production experience can ensure that lost time is avoided and the production process need not be reorganized, so that continuous production can be maintained.

Outside aids to flexibility

Building requirements are extremely varied; buildings consist of several composite subsystems. So a single system, even a flexible one, cannot meet the requirements. As occasion demands, production equipment will have to be replaced as well. Physically this is not difficult, as it is dismantled in any case after a product has been completed. But the change may be difficult financially if the capital is lacking. In such cases flexibility can be enhanced by hiring or leasing, or by greater division of labour.

Enhancement of the division of labour has long been a characteristic of industrial development. The aim is to confine the risk to a single area or to increase efficiency through independent contracting. This tendency must be consciously applied, and new forms of organization must be reckoned with in the course of development.

Equipment hire allows the contractor to alter production as required within a short time, without investing capital. Leasing provides a longer-term solution. Assessing the flexibility of the equipment to be selected is a technical matter and one to be solved by development. Assessing the comparative advantages of investment development and leasing is a task for economists. The proportion of return to outlay is determined by the market, and there are some suitable methods available for this.

Technologically inherent flexibility

In developing flexibility the first thing to examine is the scope inherent in the technology itself. The assessment of flexibility can be made either from the product angle or from the angle of the technological possibilities. In the former case, one examines the ways a particular product to suit user requirements can be produced. A single product, even a perfectly identical layout can have several technological processes, or at least several technological levels assigned to it.

According to this concept, the product is predetermined and unalterable, and the technological arsenal must be adapted to the specific purpose. No account is taken of investment costs: instead the aim is full supply of the market. A plaster building unit can be produced either manually or by an automated manufacturing system, depending on the quantity required.

The other concept is an examination of the technological scope. Reduced to an absurdity, the only producible product is what the production equipment, in an unchanged form, is capable of producing, irrespective of what the product's function and field of application will be. This situation is encountered in cases of extreme quantitative shortage.

Technology may be decisive in other cases, too. Provided product quality is the decisive factor, the cost of the process is of secondary importance. New products, if there is a demand for them, in themselves create a shortage. They are in demand even if produced by the expensive technology to hand. The extension of application then raises the demand for serial production and allows targeted investment to be made.

Owing to the long service life of buildings, neither of these paths can be followed in the building industry. With imposing, custom-built public buildings neglect of the cost factory may be tolerated, but only within strong limits, because the social system is not a despotic one.

The task is to make the product — the house — in the most individual way possible while modifying the technology to a limited, so to say socially acceptable extent. The adaptation of the technology must be great enough to allow the work to be performed in a variable environment: This factor is the adaptability of technology. The other factor is inherent flexibility, i. e. the scope for changing the product. The change may be manifest in a different quantity, leaving the layout identical, or the opposite may occur: the available capacity may be used to produce a variety of products.

The concept and development of technology

Before considering the relation between the two technological capabilities — adaptation and inherent flexibility — let us consider the elements of the technology. To do so we must find the widest definition of technology but at the same time an engineering one. Aurelio Pecceli's formulation: "Technology is the extension of science," may start a rather long train of thought. However, since every element that causes variation must be reckoned with, this formulation will be a useful guide.

Technology embraces the means and expertise of transforming materials (under the prevailing conditions). The variation of climatic conditions may result in significant alteration of technology. The simplest case of this is the difference between performing a task in summer and in winter. Since the building market has world-wide or at least regional dimensions, its technologies need a high degree of adaptability in all their elements. One might say that technology is virtually cosmopolitan and indifferent to the various regions but the expert's comment will be that only appears so to the layman. The properties of a material change under environmental influences. The equipment used must at least be supplemented so as to provide the conditions originally identified as optimum.

Almost invariably this is the course adopted, although in theory it is possible to adapt the materials and technology to the new conditions. One might even go so far as to say result can even be superior to the original one. After all, that is what is happening now with the development of space technology. So why is this course rejected? Partly because the differences are not sharp enough, and partly because inertia prevents us from acquiring the large amount of new knowledge required and applying it in practice. Consequently, the adaptability of technology has to be confined within the limits of training.

The need to adapt may activate and cause the application of concealed but existing knowledge. To establish a balance among the complexity of problems, the sophistication of systems and the variability of the environment requires that such hidden reserves should steadily increase: the demand for increased adaptability caused a demand for continuous development of training, with emphasis on intelligence and creativity. It is here that the problem of processing information emerges, and this also requires equipment. The use of a computer would seem to offer relief from time-consuming problems, but the opposite has often been true in cases of computerization coupled with an underdeveloped infrastructure, largely unskilled labour and too few qualified staff. After initial, sometimes spectacular success, the system has failed.

The first case, in which equipment is supplemented and new measures are taken is only feasible so long as the resulting extra costs can be recovered. Once this limit has been set, the requisite measures can swiftly be taken. Failing this, one must have recourse to methods of training and technology which require significant inputs of time and money. If these alterations extend beyond one specific task, one terms it a development task, and if they bring about long-term, essential changes, it can be described as a research task.

Flexibility of technological elements

The technology devised for a particular group of products can essentially be divided into two, not inherently independent types of process: direct material technology, and material-handling technology.

The course of raising the flexibility of direct material technology can be pursued by installing auxiliary equipment and tools to keep the technology continually ready for operation and to reduce or eliminate the time required for doing so. To achieve this in the development of production equipment, functions can be amalgamated to create multipurpose equipment or units with a complex function.

In the building industry, the chance to install equipment and operate it continuously is restricted because the site is not permanent. Adaptation time may be reduced by using the "basic engine + tool" system. In this case a simple tool is replaced instead of the complete machine or production system. This has been made possible by hydraulic systems, and recently by microprocessors, which have been widely incorporated by manufacturers, and are more useful still in centrally located equipment. The other course is to create complex systems, and this is an area in which considerably development can be expected. Container-mounted machine lines, for instance, will be systems of this kind. The dimensions and handling system of the container permit a fully equipped plant to be accommodated in the container. Just as holiday caravans can be plugged in at camp sites in minutes, so can technological containers, of which even several units can be connected. A concomitant to technological development is an increase in the division of labour in society, preceded by specialization of production within a specific process, increasing the number of production stages required. This division can either be eliminated, or as specialization continues, some of the partial processes can be united.

This is important because in the building industry, the requirement is to make special equipment for special processes repeatedly available, the number of switchover steps for material handling and equipment is increasing. A complex layout of equipment reduces the number of rearrangements required (internal material handling), so improving efficiency.

Material-handling processes are more flexible than production processes by their very nature. Transport systems generally are limited in terms of the weight and volume they can contain. The effects of temperature, noxious fumes, and so on are occasional, and rather infrequent in building.

The perfect universal variants of material-handling systems are container systems for variable purposes incorporated into a mobile unit. Using special equipment, the range of applications may be extended to include for instance, the transport and loading of concrete components. A container transport system is deficient if the external transport system is lacking. By connecting universal and special elements, a transport cum-material handling system of maximum flexibility and efficiency is obtained. This links up to the attainment of flexibility in the technological process as a whole.

The rate of changes may soon reach a level that prevents any separation of production and transport processes even temporarily, and the technological process as a whole. If this is not recognized in time, the system will become excessively rigid and expensive.

The most expedient way of transforming an entire technological process is to omit work phases in some cases by introducing new materials or tools. (The number of work phases may possibly increase, but this is not the aim.) It was recognition that launched prefabrication, initially on the building site right by the place where it was to be applied. The result of this development is well known. Initially, the technology of reinforced concrete structure was modified to a small extent, but the change came to affect the production and handling processes as a whole. As in this case, a radical change can even cross the boundaries of technology.

In selecting technological items, one can pursue alternative courses, either directly adjusting them to the product or making them flexible. The costs of items directly adjusted to the product have to be fully recovered, in conformity with the length of the production series, or they have to be cheap enough, which comes to the same thing. This requirement is not always fullfilled as stated in the introduction, because the units in the particular structural system may differ in length of manufacturing series but raise identical quality requirements. If, under such circumstances, the products cannot be unified, the technological equipment needs to be made flexible. But this is only possible in possession of adequate knowledge of the group of products. Where resources are limited or delivery dates are short, it is advisable to use specialized but inexpensive items, as demand in this case can be met merely by utilizing the available systems, with a minimum of change required.

The processing of information

Assuming the availability of a fairly long time, sufficient capital and clear-cut objectives, the elements to be made flexible must then be specified within a development project and the technical conditions for flexibility must be ensured.

One of the major tools of flexibility is the computer, i. e. its integration into production systems. CAD-CAM — Computer-Aided Design — C.-A. Manufacturing Conditions in the building industry do not favour wide application of computers, although they are taking an increasing part in the overall process. As yet, production equipment incorporates microprocessors at most while main computers are operated in the back-up industry for the building market.

The imperative of levels of technology

The application of computers is still largely restricted to data storage for O and M of building. In building, every house is a prototype or almost a prototype, and so much of the large amount of information about each is new. Building sites are physically remote from depots, and in case of trouble the possibilities of intervening are limited. This can be compensated for by adequate information and transport systems and by a tight backup of organization. A system of this kind requires highly qualified labour to operate the computers at every stage of production.

The objective set for centrally located industry is also a novel one. The previous concept, which favoured increases in production volume and subordinated all activities to this purpose has changed in such a way as to relate the technological system to management. It is no longer the quantity of products but the rapid adaptation of products to market conditions that counts. A condition for this is a similarity of knowledge and information, the identity of the information structure.

In building, an identity of information structure has been attained, but the quantity of information to be processed is enormous, because of the great variation in the dimensions of the "products" and the multiplicity of the materials being used. It is necessary to restrict the flow of information requirements, and it should be emphasized that this is also necessary because of the dispersal of the industry. It should be noted, that by comparison with permanently located industry climatic effects occur with such randomness that they may considerably disturb the organization of process.

A reduction in the demand for information is necessary, moreover, because of the building circumstances and the almost total lack of on-site infrastructure. In permanently sited industries, data input can occur at the same time as the information is "born". On construction sites this is not possible at the present time.

The level of required information can be reduced by product integration and by introducing a new engineering concept of the product structure, as outlined in the first part of this paper. It may indeed only be possible to decrease the amount of information generated if production reverts to skill-based craftsmanship using few kinds of materials. In such production, design and construction are in the same hands and an intricate flow of information becomes superfluous.

However, craft production cannot be restored not even in the service of flexibility since in that case there is no way of eliminating heavy manual labour or of producing on the scale required. The quantities required are small only by comparison with the automated target systems. Moreover product quality has long been determined by production systems with high equipment requirements, and the market does not allow that demand to be ignored. The way to solve the conflict between quality and volume is through a flexible system. However, the degree of freedom of the new system has to accord with the technical level already achieved and with the probability of change. Measuring methods are available for this purpose, but gradual development has to be kept in mind, precisely because of the problem's complexity. One has to resist the temptation of returning the entire system to the earlier technical level, which could be restored fast and cheaply, since in this case a growth of flexibility will only be possible at the expense of efficiency.

If changes are more frequent than the period for recovering the investment permits, the system is inflexible. Otherwise it is flexible: the relevant data can be quantified and the emerging alternatives can be ranked.

Conclusions

Technological development is a strategic problem, since the earlier, product-centred approach must be replaced even in simpler cases by the approach of a product-group technology system, dictated by the market.

If this change is to become a trend, as competition requires that it should, the extension of its application will become a constantly increasing task that outgrows the frame of one company or even one industry.

The size of the task requires an increase in know-how trading and the creation of central programmes. The latter are clearly needed to help with problems of society-wide dimensions or involving fundamental research.

The life cycle of products is giving way as a yardstick to the life cycle of technologies. This places a much higher responsibility on those who formulate new concepts. When steam as a system of railway traction was replaced by electricity, there were a fairly high number of alternatives available within the fundamental concept.

In future one must be prepared both for the increased likelihood of major conceptual changes and for the supply of the market with alternatives that meet every demand, with the aid of flexible technology.

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