Chapter 2

Theories and Principles of Design Economics

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1.   INTRODUCTION

Factories, offices, housing, hospitals, schools, roads and airports are all essential for human development, industrial production and productivity to enhance socio-economic development. However, a central problem in economics is scarcity of resources as human needs are unlimited whilst the means or resources for fulfilling them are limited. In the context of the built environment, appropriate design choices have to be made based on the resources available to meet the construction needs of owners and users which have to be balanced against the needs of society. Design decisions affect the built environment as there are economic, social and environmental consequences associated with construction projects, their use and performance. There is therefore a need to evaluate design not only from an economic perspective (incorporating capital and operating costs) but also in terms of the environmental and social costs to clients and other stakeholders (e.g. local people, businesses, communities and special interest groups).

Understanding the theories and principles of design economics is fundamental in addressing the needs of clients in achieving a cost-effective building requiring an optimum trade-off between capital and operating costs, environmental and social costs. Environmental and social costs are important in design due to externalities associated with the construction process, use of buildings, growing resource problems, and carbon emissions causing global warming and climatic disruptions.

This chapter explores the theories and principles of design economics. It starts with an overview of the factors affecting design costs and benefits, followed by a discussion of capital cost theory and the whole life cost theory to ensure that the effects of design decisions are fully considered. Value management theory focusing on maximising the function (or quality) of a design solution whether it is design space, component or materials in relation to its cost is also examined. This is followed by a discussion of the 'value of design' theory which helps to understand the relationship between economic cost (wider economic impact of attractive buildings and settings, social cost (enhanced individual, and social well-being or quality of life) and environmental cost (greater adaptability, energy efficiency and environmental sustainability). The chapter concludes with the resource-based theory which argues that construction cost is the sum of resources required but the resources required are a function of resource production coefficients and unit resource costs determined by types of buildings or infrastructure and forces of demand and supply in the resource markets.

2.   FACTORS AFFECTING DESIGN COSTS AND BENEFITS

A facility or building's function strongly influences its design which in turn affects the construction *cost*. The *function* is important as it expresses the intended use or benefits of a project and determines the design parameters. As a result, construction costs are often expressed in *functional* units (e.g. cost per beds/seats/places/spaces etc.) for

offices, houses, schools, hospitals etc.). However, construction cost is also affected by other factors such as geometry and spatial arrangements (e.g. height, *layout/groupings,* and inter-linkages between buildings, common services, and shared elements) and the characteristics of the site in terms of access for delivery, available services, and proximity to other buildings.

Traditional theories of design economics focussed on a number of key variables and their implications in terms of capital costs. For example, the geometry of a building in terms of size, shape, arrangement and height, affects capital costs. Complex design projects characterised by difficult geometry are more expensive than simple (often repetitive) projects which benefits greatly from a reduction in unit costs as a result of the learning effects or experience curve. Complexity affects costs as projects with unusual, untried and untested design features are extremely difficult to plan, construct and manage. Uncertainty and risks are also greater in complex projects with significant cost consequences. Capital cost is also influenced by other factors such as planning requirements, building regulations and taxation and capital allowances system. However, there is increasing evidence that other design factors such as colour, lighting, sound, aroma; landscape are also important. Some of these design factors can have a positive influence on the outcome of a project such as patients' recovery rate in hospitals, office productivity, and absenteeism. For example, in a recent study, it was reported that 'the provision of outdoor view reduces patients' stay time by, on average 13.5 hours and stay time by 4 hours per 100 lux increase of daylight. Other examples of the economic benefits of good design include greater efficiency and productivity, savings in tax and capital allowances, reduction in staff costs, insurance costs, accident, pollution, landfill charges and energy costs resulting in a better use of the asset and return on investment.

Determining all the potential design factors influencing construction cost is therefore important in developing an effective design solution but the challenge is often how to put a 'value' on certain design outcomes such as patients recovering earlier in a hospital as a result of better landscape view, sound and lighting performance, savings as a result of productivity, reduction in absenteeism, reduction in pollution, carbon emissions and scenic values. The impact of design decisions can be summarised in terms of costs and benefits as shown in the matrix below (Table 2.1).

Table 2.1: Design costs and benefits matrix

COSTS	BENEFITS/ VALUE
Easy-to-Price Costs **Economic** – land, planning, design cost, construction cost	**Easy-to-Price Benefits** **Economic** – asset value, rental or sale income, normal and enhanced capital allowances
Not-so-easy to price Costs **Environment** - pollution (emission cost), carbon cost, scenic values lost etc. **Economic** – operation cost, insurance cost, loss of property value etc.	**Not-so-easy-to-price Benefits** **Social** – staff morale, comfort, etc. **Economic** – productivity, hospital recovery rates, savings in staff costs etc. **Environmental** – savings in energy,

In theory, the total cost associated with any project is the sum of the project's economic, social and environmental costs. Traditionally, the client is normally concerned with direct easy-to-price economic costs and benefits that are visible and associated with **land purchase, planning, design and construction costs, rental, sales income and tax savings.** However, other indirect not-so-easy-to-price benefits (or savings as result of reduced carbon emissions, flooding damage, productivity), social and environment costs (e.g. noise and air pollution, traffic congestion, and increased flooding risks) imposed on society, governments and other stakeholders are increasingly important. For example, energy efficiency certificates are now available to buyers/tenants which affects property value/rent.

Total Project Cost = Economic cost + Social cost +Environmental cost

To mitigate the effects of market failure, some social and environmental costs are passed on to clients or project owners through regulations such as charges, taxes, planning requirements or building regulations. For example, to comply with the need to reduce carbon (or environmental cost), a local authority or planning agency could request for a higher BREEAM/LEED rating for a particular development, or an increased level of flood protection or safety margin to reduce the negative consequences of a project. In the UK social costs are incorporated by statute within the Department for Communities and Local Government (2013).To this end in England and Wales, the planning obligations (s106 T&CPA 1990 *as amended*) and payments arising from Community Infrastructure Levy (s206 Planning Act 2008) are also used to ensure that project owners contribute to the additional social costs arising as a result of a new development. This could for example mean the provision of schools, health, community and recreational facilities, bicycle lanes, and widening of some roads in a development project.

3.   CAPITAL COST THEORY
The capital cost theory of design economics was developed after WW11, largely in the UK. Most construction work, unlike today, was instigated by the Government sector. Post war budgets were meagre and politicians were eager to produce more for less, or to maximise the benefits given the limited resources available to achieve economic

efficiency. Clients wanted to maximise utility from a project by minimising capital cost subject to certain restrictions such as building and planning regulations. This resulted in some remarkable innovative thinking at the time. There can be few better accounts of this period, than that related by James Nesbit, a quantity surveyor of that era, who has provided a history of the period 1936-86, in a publication titled "Called to Account". Nesbit (1989) and his contemporaries were effectively the first "design or construction economists" and were in the forefront of the development of cost yardsticks (a measure of acceptable value denoted in many forms i.e. cost per M2, cost per bed space, cost per person according to building type), elemental cost planning and building cost modelling. For example, Cartlidge (1976) noted that in 1967 the then Department of Environment in the UK issued a circular to local authorities titled 'Housing Standards, Costs and Subsidies', which together with subsequent revisions formed the basis of the housing cost yardstick. Similar yard sticks were developed for hospital projects by the Department of Health and Social Security and for school projects by the Department of Education and Science. These documents used the elemental cost analysis of previously constructed buildings not only to measure the quantum and cost of a new building, but to derive relatively simple design related formulae (such as wall to floor ratios) to enable designers to evaluate the economic complexity (and subsequent viability) of their buildings. However, this theory is sometimes criticised due to the heavy reliance on cost/m2 capital cost guidelines for different types of buildings derived from historic data. As Sorrel (2003) noted 'the risk here is that the use of these rigid guidelines can bias clients against energy efficient buildings' required in new types of design to cope with the requirements of today's society and environmental pressure.

Since the late 1950's much has been written about design and cost planning as well as cost modelling of buildings (see for example, Seeley 1972 , Bathurst and Butler, 1973, Cartlidge, 1976, Ferry *et al* 1999, Ashworth, 1999, Ashworth and Hogg 2000 and similar books). These books on traditional design economics focussed on factors affecting capital cost, primarily building geometry and materials. For example, there are a number of principles associated with minimising the capital costs of buildings such as external wall-to-floor ratio (known as a quantity ratio) – the lower the ratio, the more economical the design, the POP ratio, plan shape, building size (economies of scale), planning efficiency, density, building layout, the effect of height, quality factors and site characteristics. The POP ratio is used as a measure of compactness of the design, the higher the percentage, the more efficient the design. This is generally true except for the circle.

$$\%Compactness = \frac{2\sqrt{\pi A}}{P} \times 100$$

A = covered area of a typical floor area,
P = perimeter enclosing that area

The capital cost of a construction project (C) is a function of a number of design variables such as quantity ratio (Qr) size (Si), shape (Sh), height (H), materials specification (M), density (D) and planning efficiency (P).

C   =   f (Qr, Si, Sh, H, M, D, P ……..)

For tall buildings, for example, Lee *et al* (2011) developed the high-rise premium ratio as part of the schematic cost estimating model (SCEM) 'to identify the productivity ratios of super tall buildings and to simulate construction cost as building design changes. They found that construction cost increases as unit cost rate rises due to the lower productivity ratio in projects with higher number of storeys. Table 2.2 provide examples of design variables and parameters affecting construction costs.

Table 2.2: Examples of design variables and key considerations

Examples of Design variable	Key considerations	Objective
Plan shape Some shapes are more economical than others Spatial arrangements influence building cost Complex shapes are more expensive	External wall-to-floor ratio (or quantity ratio) - the lower the ratio the less expensive the building Unusual features Roof complexities Natural lighting	Finding the plan shape which is the most economical
Building size Small buildings generally cost less but are not economical	Wall-to-floor ratio Discount on bulk purchase (economies of scale) Co-ordination and project management requirements	Finding the optimum size of a project that the team can cope with to benefit from economies of scale. Beyond this point there is diseconomies of scale
Planning efficiency Usable area varies (Net Floor Area)	Circulation space/ corridor areas/ Service areas/ toilets/ lifts	To minimise non-usable space (or maximise rental income) subject to planning and building regulations
Building layout/groupings Nature of inter-linkages between buildings reduces costs	Common services Shared elements/ external Walls (e.g. terraced/ semi-detached housing)	To maximise common services and shared elements which will minimise construction cost
Height Tall structures are generally associated with higher construction costs due to vertical transportation logistics, and engineering problems	Foundation costs per m2 of GFA decreases Roof costs per m2 of GFA decreases More space for recreation/car parking Site density can be increased **However cost may start to rise due to:** Foundation loads (piling may be required) Use of plant/ equipment (hoists, tower cranes) lifts, safety considerations	Finding the optimum height of a project to reduce cost (cost/m2) associated with tall buildings (e.g. piling, wind loading) and need for services (lifts, fire escape etc.)
Quality factors Level of specification (materials) affects cost	Floor/wall finishes Services Fittings/technologies Environmental rating (BREEAM or LEED)	To find appropriate specification to maximise client's utility and minimise cost
Site characteristics affect building cost	Access/roads/parking Slope/ground conditions Services Location/adjacent structures	To minimise cost relating to site characteristics and surroundings.

Cost planning techniques have now been in use for almost half a century by designers and architects, although there is limited research to establish whether cost modelling has significantly reduced building costs. However, anecdotal evidence would suggest that the building team (at least in terms of the key sectors of housing, education, health, factories and warehouses, commercial and retail) do at least consider these factors.

The UK is considered to be leading Europe (and arguably the world) in the latter half of the last century, in the field of construction economics, but would appear to remain one of the most expensive places to build in the EU. According to Cartlidge (2006), the cost of building hospitals per M2 is undoubtedly cheaper in France than the UK and a study produced by BWA Associates (2006) for the European Commission, cites the UK as the least efficient in Europe. Government led reports such as Latham (1994), and Egan (1998) in the UK have therefore focussed on procurement methods in an attempt to improve efficiency. Given the current lack of funding, albeit for entirely different reasons, the UK Government is perhaps not surprisingly re-examining the issue of efficiency. The UK Government (2012) is promoting BIM as an integrated management tool, simultaneously establishing "cost targets", and developing benchmarking and performance targets together with the RICS .(Martin, 2012). This will effectively establish average costs for similar buildings and examine methods of reducing those costs by 10-20 % to enable Government to achieve value for money. The cost plan (which summarises the capital cost on an elemental basis), has become arguably, the client's most useful document in terms of cost control, which even in the new age of BIM (Building Information Modelling) is unlikely to be replaced. However, as Crotty (2012) has muted "currently cost planning is somewhat of a "black art" but BIM is likely to provide greater transparency and accuracy of information and knowledge of risks that will enable costs not only to be speedily established but interrogated with relative ease. BIM does nevertheless provide a challenge to traditional cost modelling and estimating. It is capable of providing for the first time detailed knowledge of resource costs, planning and scheduling of resources, which whilst not changing the fundamental economics of efficient building shapes, may make traditional methods of cost modelling redundant.

4.   WHOLE LIFE COST (WLC) THEORY

Whole life cost theory, often referred to as 'cost-in-use' theory, is an extension of the capital cost theory by including the long-term (operating) costs associated with the use of a building. It focuses on establishing a trade-off between the initial short term (capital) cost and long-term (operating) cost of alternative design solutions. To avoid inefficient use of resources, Bathurst and Butler (1973) argued that the '*full economic effect of the various design decisions taken by the architect can only be examined if capital and long-term costs can be represented together*'. The design option with the lowest whole life cost (i.e. capital and long-term costs combined) is selected as the most efficient economically subject to certain restrictions relating to the minimum performance criteria to ensure that all options comply with minimum specification. Sometimes the term 'whole life appraisal' is used where cost and performance as well as benefits are considered.

Whole life theory attempts to establish the total cost of a facility measured over the period of interest of the owner and the objective is minimise the total cost of the design over the building's life span and to maximise the client's utility (benefits) from the

facility. It is sum of all funds expended for a facility from its conception to the end of its useful life and includes the initial capital expenditure (CapEx) for planning, design, construction and the operating expenditure (OpEx) for maintenance, energy, cleaning costs, taxation etc. There are economic and environmental incentives provided by governments to influence design choices or preferences in favour of energy efficient or carbon friendly design solutions through the capital and enhanced capital allowances/taxation system to reduce a project's capital and operating expenditure. WLC theory is based on quantifying all significant costs during the life of a facility using present value/ discounting technique as the costs are incurred at different time periods.

It recognises that all costs (and benefits) arising from a project are relevant for investment decisions and can be used for realistic estimating, budgeting and cash flow analysis. It is used for making choices between design alternatives to address design questions such as the following: Should uPVC, wooden or aluminium windows be selected? Should a particular type of roof or heating system be chosen? For example, a client might want to make a decision between carpet and wooden floor finish. The initial cost of a carpet might be lower than wooden flooring, but the running costs will be higher due to the number of replacement and higher cleaning costs associated with a carpet. The carpet may have to be replaced a few times more and cleaned more frequently compared to the wooden floor finish which may last longer (requiring less replacement) and less cleaning due to its surface.

There were a number of studies carried out in recent years, for example, Construction Excellence 2004, to test the whole-life Cost (WLC) theory. Its use is increasing for a number of reasons. First, both public and private clients are changing. Public sector clients are being encouraged to take a whole life approach and to discontinue the practice of separating capital and recurrent budgets. Second, there is an increased awareness from private sector clients in considering whole life performance in making long-term investment decisions. Other reasons for the widespread application of whole life theory includes the growing use of alternative integrated procurement systems combining design, construction and operation (e.g. DBFO, BOT,PPP/PFI), the environmental debate on energy use and long-term effects on global warming as well as the growth of facilities management (FM) industry. WLC provides the basis for creating a sinking fund to finance the operation and planned maintenance programme for the effective management of a facility.

Key factors to consider apart from capital and operating costs are the *minimum performance specification* required to compare design alternatives. For example, for a floor finish this could be thermal properties, slip resistance, life expectancy, and appearance/ aesthetics. The *period of analysis* to be used for the evaluation could be the building life, functional life, economic life, or legal life. WLC is a useful theory but there are a number of problems associated with its application as it involves *long-term forecasting* which can be difficult due to policy, economic, environmental and technological changes. There are also difficulties in obtaining reliable and consistent data due to variation in practices relating to *data collection and analysis*. Maintenance costs are very difficult to predict and even where they exist, historical data tends to be variable and problematic due to the age of buildings, changes in design and construction methods, changes in performance specification, different level of use and maintenance

policies. There are also problems associated with selecting a reasonable *period of analysis* (which depends on the type of building and client), and *life cycle* i.e. whether this should be based on physical, functional or economic life and how quickly is the building likely to be obsolete. A major challenge is therefore to overcome the difficulties in collecting data and predicting the lifecycle or lifespan of buildings, components, systems and materials due to the technological revolution, evolving practices and changes in procurement policies.

Economic factors such as discount rate, inflation, interest rates, taxation should also be determined to calculate the whole life cost of design alternatives. However, there are problems associated with selecting an appropriate *discount rate. A* high discount rate means future costs are heavily discounted which can encourage short-termism, whereas a low discount rate means future costs are highly valued. The discount rate reflects the client's long-term cost of borrowing money or the opportunity cost of capital and depends on *interest rates* and *inflation* which are both difficult to predict. There are also problems associated with differential inflation as some costs such as energy tend to rise faster than others. Predicting the impact of *taxation and tax relief* can be problematic as there are two types of expenditure associated with WLC - capital expenditure and revenue expenditure. Revenue expenditure (operating costs) is tax deductible, whereas capital expenditure generally is not. However, some capital expenditure qualifies for tax relief but only for some types of building and parts of buildings – for example 'machinery and plant component' but this can be very complicated. Tax relief must be included in WLC calculations for clients who pay tax.

5. VALUE MANAGEMENT THEORY

Value management evolved from the work of Lawrence Miles during WW 11. Although the terms 'value analysis' (VA) and 'value engineering' (VE) are sometimes used interchangeably, value management is increasing used to capture both VA and VE. Design value generally means worth, significance, importance, use/usefulness or esteem associated with a particular design solution. Value therefore depends on the level of function (or quality) of a design, design space, design component or materials in relation to its cost.

$$Value = \frac{Function}{Cost}$$

According to the function-cost ratio, value is increased either by reducing the cost of a design through identifying unnecessary costs or maximising the function (or quality) of a design for a given cost or project budget to achieve economic efficiency. Shen and Liu (2004) argued that its 'underlying hypothesis is that the cost of an element/component should match the importance of its realised function(s)'. The basic philosophy of value engineering is therefore to remove unnecessary cost with no loss of function and hence to increase value.

Unnecessary cost is defined as 'cost which provides neither use, nor life, quality, appearance or customer features' (Kelly and Male, 2002). Unnecessary cost can occur due to 'unnecessary' design components, materials, lifecycle, or poor build-ability. In economic terms, this reflects an inefficient use of resources which requires intervention in the form of value management. Sorrel (2003) noted that VM solutions are designed to 'optimise the level of expenditure, whilst meeting all the client's building requirements (i.e. minimize cost of building and maximize client's utility).

The value management theory recognised that it is useful to have a 'second look' at key design decisions to explore value opportunity interventions to reduce the cost of a design solution without sacrificing the function (or quality) of the space, facility or building. Design efficiency is achieved when the benefits (from additional function) is greater than the additional costs involved. Evaluating a design solution through a value management or value engineering process provide benefits as different teams/stakeholders (e.g. clients, users, architects, engineers, quantity surveyors and other specialists) can examine the same design to identify waste or inefficient use of resources in terms of unnecessary functions (and cost) which is crucial in large, complex and innovative projects, particularly at the early stages. VM can result in a reallocation of resources to improve design in other areas of the building to produce greater benefits or utility to the client.

There are several definitions of value management or value engineering approach. Dell'Isola (1982) is his seminal work defined it as a *'creative organised approach whose objective is to optimise cost and/or performance of a facility or system'*. Kelly et al (2002) argued that it is proactive, creative, problem-solving service that involves the use of a structured, facilitated, multi-disciplinary team approach to make explicit the client's value system using a variety of strategy, tools and techniques such as Pareto's law of misdistributions (Shen and Liu, 2004), function analysis and issue analysis. For example, Pareto's law helps to identify significant elements in a building that comprise 80% of the project cost as the focus for value management. Function analysis is a powerful tool that can be applied to design spaces (e.g. board room, bathroom, classroom, and store) or component and elements (e.g. windows, cladding, roof, floors, heating system etc.). Money can therefore be saved by eliminating unnecessary costs associated with unused spaces in the board room, bathroom, classroom, and store and/or by selecting elements and components that are fit-for-purpose. To apply this tool, a series of questions central to the design proposed are asked such as what does it do? and what alternative will perform the same function? It is important to identify primary functions core or essential to the design and secondary functions not essential and possibly avoidable. Examples of primary functions of a window are to control ventilation, exclude moisture, transmit light, and improve security **and** its secondary functions are to enhance appearance, reduce sound, and assist cleaning. However, what is secondary or primary function depends on the context of the project and the client's brief. What is a primary function in a given situation could be a secondary function in another context and vice versa. The use of function analysis should be complemented by other tools such as issue analysis to resolve high level problems in clarifying, defining, and developing a client's brief and design specification.

There are different methods employed including the 40-hour workshop, VM audit, and contractors change proposal depending on the stage of design and the objectives of the VM exercise (Perera et al, 2011). Examples of savings from VM are shown in Table 2.3.

Table 2.3: Examples of Value Engineering Savings from Selected Studies

Project	Cost	Savings (%)	Participants	Sources
New university building	36 M	8.4%	Design team & client representatives	Shen and Liu (2004)
14-mile underground railway	3,200 M	3.5%	Contractors & VM expert	Shen and Liu (2004)
3 Railway stations	48 M	36%	Contractors & Internal VM manager	Shen and Liu (2004)
New chemical factory	37 M	15%	Original design team and client representatives	Shen and Liu (2004)
Case study A		£835,000	Entire design team, contractor and client	Perera et al, 2011
Case Study B		£1.5 m	Entire design team and client	Perera et al, 2011
Case Study C		£2.5 million	Entire design team and client	Perera et al, 2011

6.   VALUE OF DESIGN THEORY

Worpole (2000) in his book titled '*The Value of Architecture: Design, Economy and the Architectural Imagination*' argued that good design can contribute in terms of the 'wider economic impact of attractive buildings and settings (economic cost) …enhanced individual, and social well-being or quality of life (social cost) and greater adaptability, energy efficiency and environmental sustainability' (environmental cost)

The economic dimension (or project profitability or loss) of a design depends on mainly two factors - the development costs and value. The two quantifiable aspects of design are, firstly, the direct effect of design on costs and second, the impact of design on value (market rents). Good design is often sold at a premium and is usually more ambitious, intensive schemes to generate higher floor areas on higher plot ratios. The development value relate to sales, rental income, reduction in occupancy costs, greater productivity, better interaction and communication through flexible layouts which can be achieved through good design. The economic perspective reflects the view that development is usually undertaken to ensure that the cost of development is reasonable and there is a satisfactory return on investment or benefits to the developer or owner. The economic value of design therefore establishes the benefit to the developer in financial terms and in relations to all expenditures incurred by the developer including financing costs and interest charges.

Economic Value of Design (Residual Profit or Loss) = Development Value – Development Cost

Development costs include land costs, construction and associated costs such as professional fees, planning and building regulation fees, interest charges and other costs associated with using or disposing a building (see Table 2.4).

Table 2.4: The key variables in establishing development costs are:

- Land costs – price of land, stamp duty legal fees, agents fees (e.g. 1-2%)
- Site costs – ground investigation and land survey fees
- Building costs – Based on the gross area of the building and price per square metre (different methods can be used)
- Professional/management fees – usually based on a percentage of the building costs or a scale of charges, negotiated or fixed fee for each profession involved
- Planning fees - costs involved in making planning applications and securing consent usually based on local government tariff
- Building regulation fees – scale of charges depending on the building cost or size (Building Control Department of Local Authorities)
- Funding fees – incurred for arranging finance and usually reflects the size of the loan
- Finance/ interest charges – cost of borrowing money or opportunity cost (interest on land costs, professional fees and building costs)
- Letting fees – usually varies as a percentage of rental value
- Sales costs - include agent's and solicitors fee (usually a percentage of Net Development Value)
- Other development costs (e.g.; relocation, planning obligations under s106 TCPA1990 (*as amended*), charges under the Community Infrastructure Levy under s206 Planning Act 2008 plus commissioning, taxation etc.)

In terms of the social value, Worpole (2000) noted that 'good architecture and design, can have benefits and impacts beyond aesthetics – in greater feelings of safety and security, greater legibility and assurance, and in a greater sense of locality, identity, civic pride and belonging'. He further argued that, achieving this is a 'vital part of a wider notion of quality of life…..which is increasingly how towns and cities compete for inward investment and population growth'. Social dimension of design can be assessed using different methods including utility values or society's degree of satisfaction using multi-criteria evaluation or panels of judges in a design competition or during post-occupancy. Slaughter (2004) in commenting on the development of Design Quality Indicators (DQI) recognised that the high rise social housing in Chicago was a major source of social problems for the occupants 'creating dehumanizing and grim environments'. Gilchrist and Allouche (2005) developed social cost indicators (in a broader sense) capturing a range of factors affecting society as a result of construction projects such as pollution, traffic, ecological and health and economic related indicators with various valuation methods to assess their social impact.

The climate change agenda relating to carbon reduction and sustainability reflects a move from traditional capital and whole-life cost theories focusing on the economic dimension only. There is now a growing agenda to reduce waste, conserve resources by using recycled, recyclable or energy efficient materials and technologies to minimise

energy consumption through design process. These developments have provided the momentum to embrace the value of design theory that adequately captures social and environmental effects of design decisions using assessment tools such as BREEAM and LEED. The value of a design for example is reflected in the BREEAM rating/score, which involves a trade-off between the additional construction costs to achieve a higher environmental rating.

A major factor in design is to incorporate environmental considerations through better space planning, use of materials, and utilisation of buildings to reduce the embodied energy and transport related energy associated with different design solutions. The success of environmental tools such as BREEAM (BRE, 2008) has also been acknowledged but it is increasingly recognised that environmental aspect of design is intricately linked with the socio-economic dimensions (OECD, 2000; Katz et al 2005; Atwood, 2008). Cooper (1999). Many other researchers recognised the tension that exist in design decisions between protecting the environment, and balancing social and economic development needs. However, there are challenges in operationalising the sustainability (or value of design) theory (Kaatz et al 2005). An argument sometimes put forward is that the 'least sustainable [design] is the more profitable' as it avoids the environmental cost'. Sir Jonathon Porritt, Chair of Sustainable Development Commission was quoted as saying.

'You have occupiers saying we want to live in green buildings, but there aren't any. So the contractors say we can build them but developers don't want them. Developers say we want them but investors won't pay for them. Then the investors say we would pay for them but there is no consumer demand" (Financial Times, 2007).

The difficulties relating to uncertainty and investment risk (IEA, 2007), economic returns, environmental benefits, social preference are at the heart of the value of design debate. The trade-off between cost and value (economic), environmental and social dimension is therefore crucial in decision making. The growth of carbon financing, with the price of carbon established in market, or carbon trading reflects the increasing need to establish trade-offs in design between carbon emission (reducing environmental costs) and social and economic costs. *Carter* (???) argued that an integrated approach to sustainability in design has the potential to save money and increase profit margins. Carter noted that case studies have demonstrated that a growing number of developers are making a commercial strategic decision to improve the environmental and social performance of their design schemes.

Carter's model:

Sales income – Land Value – Design and Construction costs = Profit Margin + Brand Value

Carter argued that "living in a zero-carbon home, and the main attraction of having cheaper utility bills, and ultimately better living conditions and standards, should enhance the 'Brand Value' of a housing developer". Carter (??) further argued that, profit margin is directly linked with the brand value. Profit margin does not just enhance value of the brand, but is dependent on it. There is a direct correlation between the two and one cannot be achieved without the other. Profit margin will enhance and sustain the brand value and brand value can improve profit margins.

6. RESOURCE-BASED THEORY

The total construction cost is the sum of resources required which is a function of resource production coefficients and size of the project. Production coefficients determine the resource consumption rate and unit resource costs are determined by the supply and demand in the resource markets (Robinson, 2000). Construction projects require resources such as professional input for design and management process such as design labour, construction labour, plant and materials directly used in the production process (see figure 2.2).

Figure 2.2: Resources required for production
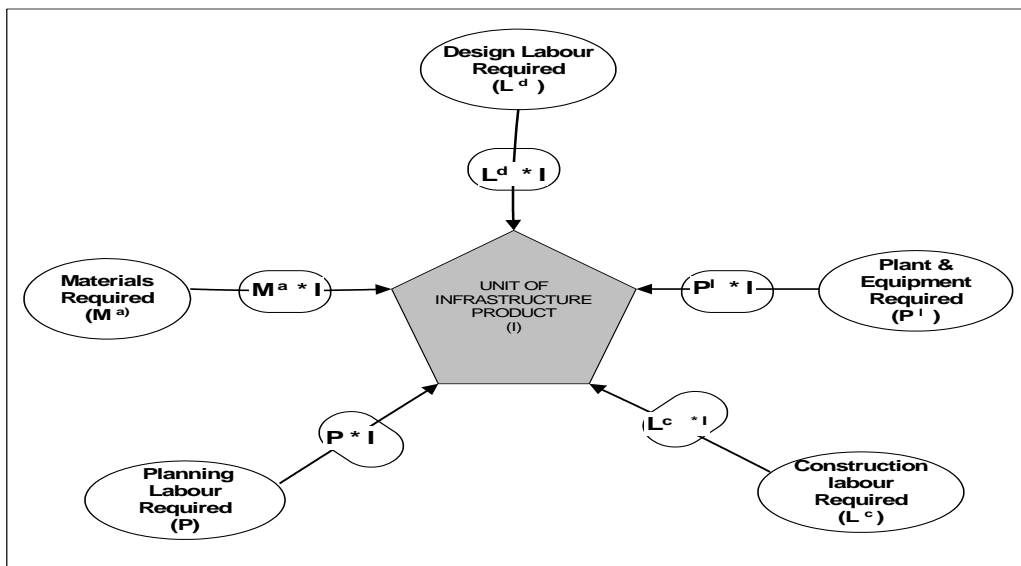
Source: Robinson (2000)

For example, construction labour include steelworkers, carpenters, electricians, painters, bricklayers, masons, plumbers as well as construction managers, and materials include aggregates, glass, cement, pipes, steel reinforcement, timber and other products. The construction labour production coefficient ($L^c * I$) is the labour requirement for a production of a unit of construction project. A 'unit of or construction' is a conceptual term expressed in various physical quantities (e.g. area, number of users, or some other measures of output). Building- type infrastructure such as schools, hospitals, police stations and houses are usually measured using the superficial area method (gross floor area). Non-building type infrastructure, mainly civil engineering structures (e.g. roads, railways, sewerage and ports) are measured in a variety of ways - superficial area, cubic volume, linear (length or width of facility), number of users or other unit of output measures. The quantity of resources required or demand (D) is a

function of the number (quantity) of infrastructure or construction projects (IQ_z) and their production coefficients (C) i.e. the resource requirements for a unit of infrastructure or construction project.

$$D = f(IQ_z\ C)$$

The production coefficient (C) is specific to each type of resource and varies according to the type of project, development type, design and construction technology methods. Similarly, the level of resources available or supply (S) is a function of existing level of resources (E), resource growth rate (G) and productivity rate (δ) influenced by training policy (e.g. costs and tax associated with training, availability of relevant educational courses and apprenticeship schemes) as well as improvement in procurement, technology, adoption of innovation in design and construction, and standardisation of design..

$$S = f(\delta, E, G)$$

Infrastructure or construction projects require resources and the rate of resource consumption (e.g. materials, design labour, construction labour and plant) during production depends on the type of infrastructure (or construction project), and the production coefficients. For example, the quantity of planning (professional planning input) required for a particular construction project is illustrated in equation (4).

$$R\,Q_j = \sum_z C_R * IQ_z \qquad\qquad (4)$$

In equation 4, there are **j** types of planning resources (**R**). The types of planning resources could be, for example, town planners, building control officers/planners, building inspectors, health and safety inspectors, environmental inspectors, enforcement officers and regulators. Similarly (in equation 5 below), there are **n** types of design labour (**L** [d]) such as architects, surveyors, and various types of engineers (civil, aerodrome, transport engineers, water and sanitation, building services, electrical and power etc.).

$$L^d\,Q_n = \sum_z C_{Ld} * IQ_z \qquad (5)$$

Equations 6 also shows **p** types of construction labour (**L** [c]) whilst equation 7 shows **m** types of components or materials (**M** [a]). There are so many different types of construction materials and components in the UK market. Sir John Egan (Egan, 1998) in his review of the UK construction industry titled 'Rethinking Construction' noted that a house has about 40,000 different components compared to 3,000 for an average car. He also cited the example of about 150 different types of toilet pans in UK compared to six in the USA and argued for clients and designers in the UK to make much greater use of standardisation to improve efficiency and productivity.

$$L^c\,Q_p = \sum_z C_{LC} * IQ_z \qquad\qquad (6)$$

$$M^a\,Q_m = \sum_z C_{Ma} * IQ_z \qquad\qquad (7)$$

Equation 8 below shows **o** types of equipment and plant resources (**P**). Whilst developed countries have a vast range of equipment and plant resources, the types of equipment and plant resources are often limited in many developing countries.

$$P\,Q_o = \sum_z C_P * IQ_z \qquad (8)$$

The availability of the different types of resources outlined above depends on the existing level of resources (E), resource growth rates (G) and the productivity rates (δ). The quantity of planning, design labour, construction labour resources, materials and plant resources available are illustrated in equations (9) to (13).

$$R\,S_j = \delta\{E_j + (E_j * G_j)\} \qquad (9)$$
$$L^d\,S_n = \delta\{E_n + (E_n * G_n)\} \qquad (10)$$
$$L^c\,S_p = \delta\{E_p + (E_p * G_p)\} \qquad (11)$$
$$M^a\,S_m = \delta\{E_m + (E_m * G_m)\} \qquad (12)$$
$$P\,S_o = \delta\{E_o + (E_o * G_o)\} \qquad (13)$$

Construction (or infrastructure) costs are intrinsically linked with the cost of various resources. A scarcity of resources means that unit resource costs are likely to increase leading to an overall increase in construction (or infrastructure development) costs. In the UK, this is reflected in the development of various indices such as materials, labour, plant and equipment to show changes in resource input costs over time. Construction costs are therefore affected by the demand and supply situation in the resource markets. Traditional cost structure of construction projects is normally presented in the form of a static elemental cost plan. Whilst this approach provides estimates of likely construction cost on an element basis, there are obvious limitations to its use for resource and production management. The alternative resource-based cost planning approach provides not only estimates of cost requirements, but more importantly provides a better understanding of the resource mix and the implication for changes in the resource markets which can be better accounted for in the cost plans. This will enable cost changes as a result of the availability of labour, material and plant resources to be carefully and accurately managed during the cost planning process.

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