ABSTRACT

Buildings are an omnipresent aspect of human culture, both past and present. The diversity of these structures is emphasized by the various construction materials used such as grass, concrete, adobe or bone and also by the numerous ways in which we study them, through architecture, engineering, historic preservation and archaeology. It is argued that the 'diverse' construction methods, material components and professional approaches to analysis can be bridged through the use of Building Science. By definition, Building Science utilizes scientific and practical principles common in all built objects that ground structures into a common framework (i.e., shelter, heat transfer, etc.) and applies this framework to the functional requirements of each building. Using a cross-temporal examination of built forms in the Canadian High Arctic (Thule culture whalebone house, Snowhouse, prefabricated House) this thesis demonstrates the utility of Building Science as a holistic tool to provide new information to each of the professional disciplines that study buildings. While not a process in itself, this thesis will demonstrate that Building Science is a theoretical tool that can be used in the context of any structure, from any time period and any geographical location.

ACKNOWLEDGEMENTS

The road to completing my thesis was indeed long and arduous. I could not have done it however, without the encouragement and support of many people. To begin, I have to thank the Faculty of Environmental Design and all of the staff that continue to make the department tick. In particular, Mr. Bill was always there to save the day. My advisor, Tang Lee, has been invaluable in guiding me through the maze that was my degree, and ensuring that I didn't get off-track. Tang, I couldn't have done it without you. My advisory committee also was central to the success of this thesis. Both Malcolm Johnson and Bob Passmore, who inspired grand discussions and lively debates in our afternoon "tastings", ensured that every angle had been covered. To them, I am indebted. The support and warm meals provided by both Reg and Bonnie Jean got me through more than just hunger spells. I also want to thank Sue Fairburn for all of the late night sessions in our office. Without those I could have never developed my thoughts into a coherent whole. Thank you to my parents, Jackie and Malcolm, who always knew that I could do it, and of course my Soot who was always there and is now looking over me. And finally, I could not have even started this degree, let alone finish this thesis, without the inspiration and love of Mitch. He always saw the vision in my ideas and was the strength that counteracted my uncertainty. To him, I am eternally grateful.

DEDICATION

To Male
Who got to know a little 10 year old ...

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CHAPTER. 1: INTRODUCTION

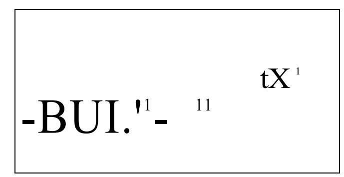
What do the Getty Centre and the Parthenon have in common? How are the Royal Palace in Cambodia and a simple house in Cape Cod similar? Is it possible to look at each of these buildings from the same perspective as an Indian grass hut?

On initial inspection these are comparisons (see figure 1.1) that embrace vastly different time periods, diverse geographical locations and seemingly incomparable cultures; comparisons that bring together buildings that are elaborate and others that are simple to the naked eye, some that are massive in scale and others that are diminutive, culturally significant architecture and culturally responsive vernacular buildings. In what context could we discuss all of these buildings on the same level? Is this discussion even possible? And would such a discussion be pertinent to either modern industry or academia? These are just a few of the questions that have inspired and fueled an exploration of buildings to establish what makes each of the examples listed part of the same species. The discipline of building science can be used to understand and link all of these structures through the use of a single theoretical perspective. However, common practice must first be investigated and understood, before a new methodology can be posited and developed.

The Getty Centre, Los Angeles, California, 1990's

Parthenon, Athens, Greece 8 century B.C.

Royal Palace, Phnom Penh,Cambodia, 1813 A D.



Cape Cod house, 18 century

Grass hut, central India, 20'" century

Figure 1.1 Buildings from different time periods and geographical locations

1.1 OVERVIEW

Building research has commonly included two main branches: 1) the investigation of individual construction components such as walls or windows or specific materials like wood or concrete; and 2) the examination of different construction phases or historic time periods. A holistic view of the building that combines these two areas appears to have been largely neglected, with the individual elements emphasized and most being treated in isolation. The result has been the development of an elaborate weaving of individual disciplines that focus on specific areas, specializing in the intricacies of their own areas. An understanding of the building as a whole seems to have been usurped by intense specialization of its individual parts.

The intrinsic concept of a building as an entity unto itself seems to have been left by the wayside; an idea not fitting with the intense specialization of today's culture. Yet each individual element of a building is part of a greater whole, part of the building. As a building is inherently a system of interrelated elements, a change or alteration in any aspect of the building will naturally affect the greater building system. The corollary is that one element cannot be analyzed or changed without implications to the building as a whole. This complex interrelationship between building components must be addressed in the face of problems in modern construction and the emphasis of recent research trends.

By changing our view of the building to encompass this holistic perspective, then similarly, the way that we view and understand buildings must also change orientation and praxis. The common body of knowledge for building technology, which presently exists as a fragmented compilation of information, must be consolidated into one discipline: the science of buildings. This discipline has the potential to span any distinct profession that utilizes the building as its focal point for research. The fields of architecture, engineering, historical preservation, archaeology and planning, for example, should consider the perspective of building science and other disciplines thereby creating a dynamic awareness of the construction, habitation and life cycle of all buildings.

Building science is defined as the study of the interrelationship of the elements that comprise the building envelope, the outer shell that separates the interior environment from the exterior environment. As every building has a building envelope, the discipline can be used to bring the disparate parts of building analysis together, creating a common platform for the analysis, discussion and understanding of buildings from different time periods and distinct geographical locations. Understanding the nature of the discipline, however, and how its structure allows for this analysis is imperative to a clear and concise use of the discipline. The objective of this thesis therefore, is to demonstrate how building science is central to interdisciplinary investigations of buildings before they are built, while they are standing, and after they have fallen down (figure 1.2). As part of this quest we can derive logic and understanding from principles that are inherent in all buildings, regardless of their physical state. Central to this analysis is understanding how all buildings can be viewed from the same perspective; and then extend this information to each of the various disciplines that make buildings their central focus.

Standing

Fallen Down

Figure 1.2 The Gibson Wright Mill in eastern Maryland in its upright and collapsed states

1.2 OUTLINE

Before we can embark on exploring, understanding and analyzing buildings themselves, we must first outline the nature of buildings. Chapter 2 will investigate the universal motivation for building and how these motivations have changed through time and geographical location. A discussion of what we build, commonly employed vocabulary and our conceptions of the built environment will lead into a discussion of the need for a holistic perspective when analyzing the built environment.

Chapter 3 will describe the discipline of building science by exploring its rudimentary framework that is comprised of three component parts: 1) the physical elements of a building; 2) the principles of materials and components; and 3) the functional requirements of every building. Each of these three areas will be described individually, followed by an exploration of their interrelationship in order to understand their role in the discipline of building science as a whole. The chapter will conclude with a discussion of the cultural influences that inevitably effect the design and construction of buildings. Although these influences are only briefly described in this thesis, it is important to be aware of their powerful ability to shape the built environment of the present and the past.

The methodology for the building science analysis will be presented in chapter 4. This will be followed by chapter 5 which will present background information on the Canadian High Arctic, the chosen area for the case study analysis due to its extremes on the building envelope. A discussion of the climate of the Canadian High Arctic and a brief history of the area will be followed by a description of the three case study buildings: a snowhouse used in the Canadian High Arctic during the late 19th century, a Thule whalebone house utilized in the early 1500's and finally a modern prefabricated Coldstream house issued to Arctic communities in the mid 1980's.

Chapter 6 will present the analysis of each of the case studies using the methodology outlined in Chapter 4. Chapter 7 is a discussion of the results of the analysis emphasizing the pertinent points that will lead to a greater and higher understanding of the discipline of building science and of buildings as they relate to one another.

Finally, chapter 8 will conclude the thesis by presenting areas for future research in building science analysis for both industry and academia.

CHAPTER 2: BACKGROUND - FUNCTION AND HOLISTIC APPROACH

> ...buildings are among the largest, most expensive and most permanent products of human labour. Their capacity to influence social and intellectual life, their role as status signifiers, their central part in the history of the world's religious and political institutions, their changing revelations of (and impact upon) domesticity, urbanity and civic awareness, are widely acknowledged
> (Harris 1999:2).

Buildings are universal features in human culture and transcend both time and geographical location. In short, buildings are an omnipresent part of any society, past or present. This ever-presence however, often renders them an unnoticed part of the everyday. They exist at all times; they are part of our lives, our history and our future. But why do we have them? Why have we needed them in the past? And why will we continue to need them into the future?

This chapter will investigate "what buildings do" in two ways. First, buildings will be presented in the context of their role as a divider and separator of the external environment from the internal environment and how the building envelope accomplishes this task. Second, an investigation of the building's historical role in society and how as cultures, societies and technologies have changed and developed, so have the expectations that people have of their buildings. A key part of this discussion therefore is to understand "what buildings do" in our society. The final section of the chapter will examine how a more holistic approach is necessary in the analysis of buildings and how this can be accomplished through the use of one discipline: building science.

2.1 WHY DO WE BUILD?

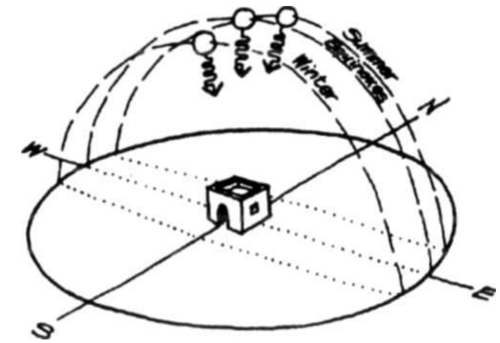
Regardless of where we live, the environment that we inhabit is to some degree inhospitable. As an example, many climates do not provide the warmth for humans to be comfortable or are simply too cold for the human body to survive unprotected. Alternatively, many environments are too hot, and people seek protection from the ravages of the sun. At both extremes, and in all environments, buildings are constructed to modify the external climate. People build for "environmental control" (Elder 1974:9) by enclosing and creating an alternate or modified interior climate that can be manipulated and controlled for human comfort. This statement raises several pertinent questions: What are we keeping out? What are we creating inside? And what are we building to facilitate this?

2.1.1 EXTERNAL ENVIRONMENT

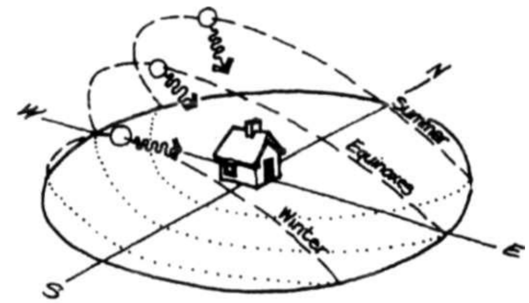
Every person is familiar with, and has been exposed to, the outside environment. It provides the world in which we live, the air that we breathe and the earth that we inhabit. The type of environment in which we live (hot and dry or cold and wet) is determined by *where* on the earth that we live. This geographical location will not only determine our relationship with the sun, it will also determine the local terrain, the regional climate and general weather patterns. Each of these factors are combined to form the external environment that makes each region unique.

2.1.1.1 The Sun and Climate

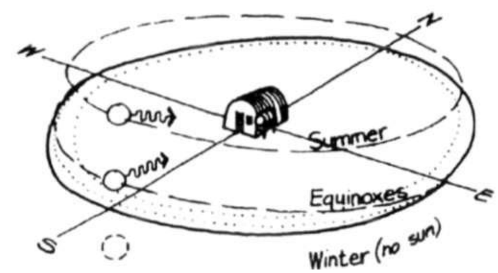
The sun is the most ubiquitous element affecting all humanity. Its rays provide both light and heat to all parts of the earth's surface. The amount and quality of light and heat heavily influences how we live and build on the earth. In fact, Edward Allen (1995:3) believes that "the sun is the single most important factor in the lives of people and their buildings." Figure 2.1 illustrates how the location on the earth will influence the amount of seasonal sun that the location will receive. As overhead sun provides stronger and more consistent heat, equatorial regions are consistently warm through the seasons, while locations near the polar zones receive less heat and have marked seasons.



Equatorial Zone



Temperate Zone



Pblar Zone

Fig 2.1 Location on the earth will influence how much sun is received and generally the climate in which you live

The interrelationship of geographical location and the sun determines the climate of a region which is defined as "the aggregate, over many years, of all the atmospheric phenomena observed at a particular place" (Sealey 1979:9). There are many and various climatic zones on the earth, but they can be summarized into five broad categories: hot and humid, hot and arid, temperate, cool and polar (figure 2.2). These climatic zones determine the seasonal air temperatures, general wind and air patterns, precipitation and humidity of a region. For example, the polar regions have low seasonal air temperatures, constant, fierce wind patterns, and very little yearly precipitation.

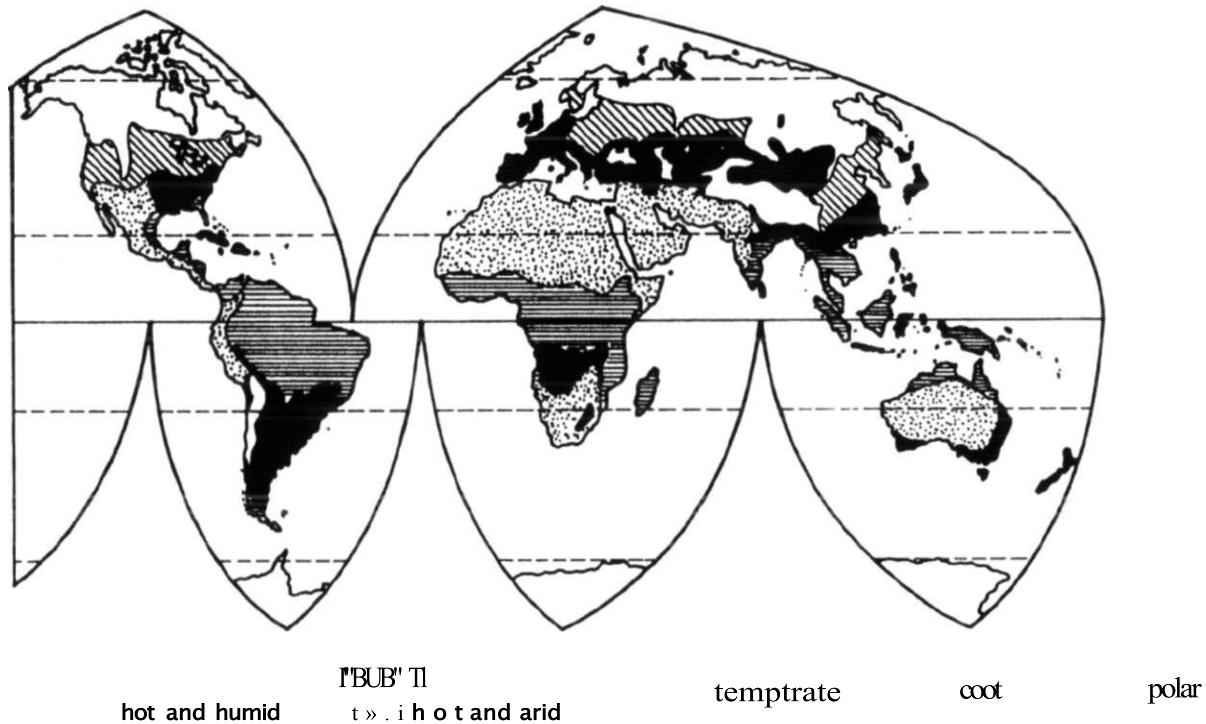


Fig 2.2 World map showing the location of the five major climatic zones. Note that the hot climates are situated around the equator, where they receive the most direct sun.

2.1.1.2 Localised Geography and Weather

Localized features of the landscape are also important determinants of the external environment and often determine the weather patterns for a region. While climate traces atmospheric patterns over years, weather is composed of individual elements such as rain, wind and sun over a much shorter period of time: days (Sealey 1979:9). Although we might inhabit a cold and dry climate, there may be both warm/wet and cold/dry weather patterns. These differences can be the result of local geographical features, such as mountains or adjacent bodies of water. Figure 2.3 illustrates how the differing weather patterns on either side of the mountain serve to influence and create the local weather.

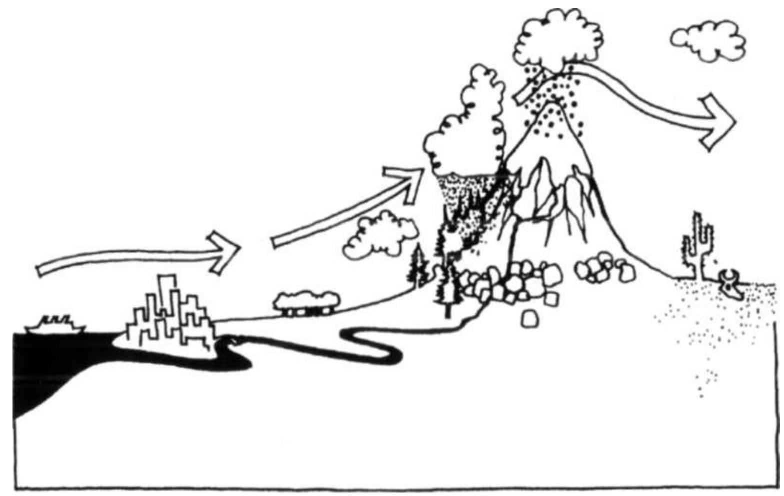


Fig 2.3 Geographic features such as mountains and bodies of water will influence local weather on either side of the mountain

2.1.1.3 External Dangers

The exterior environment is comprised of more than just the "weather" (figure 2.4). As part of the natural biosphere, there are elements that might be classified as "dangers" that could threaten human life. Large and small animals, insects and even other humans could potentially threaten human life. These dangers are in fact a prominent part of Viollet le Due's early chapters of his book Habitations of Man in All Ages (1876), where he discusses how the threat of external dangers served to motivate humans to construct shelters and control entry. While these "dangers" can take various forms they still coexist with humans and their threat is often as life threatening as exposure to the external climate.

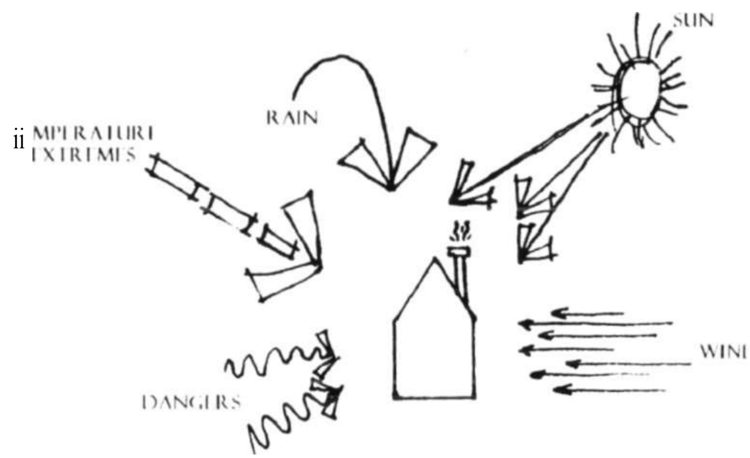


Fig 2.4 The forces of the external environment

2.1.2 HUMAN COMFORT AND THE INDOOR ENVIRONMENT

The conditions under which the human body will feel no discomfort are simple, yet explicit. Esmond Reid states in his book Understanding Buildings that the average human body functions comfortably within a limited temperature range of 18-30°C (Reid 1998:39). Although this statement seems to be a reasonable summary of comfort, there are many factors to consider when determining a zone of comfort for the human body.

The byproduct of human activities is heat. A person can generate as little as 250 Btu/hour (72.9 Watts) while sleeping or sitting (figure 2.5) and as much as 2400 Btu/hour (699.7 Watts) with extreme activity (Hutcheon 1968:1) (figure 2.6). In order for the body to continue to function at a constant 37°C (body temperature), it must either conserve or expel generated heat (figure 2.7). The criteria for comfort in an indoor environment therefore will be contingent upon the level of a person's activity and one or a combination of the following:

- ? What kind of clothes (if any) is this person wearing?
- ? What is the temperature of the indoor air?
- ? What is the temperature of the adjacent surfaces?

Fig 2.5 A person will generate very little heat sitting at a desk

Fig 2.6 An active person will generate significantly more heat which is transferred into the surrounding air

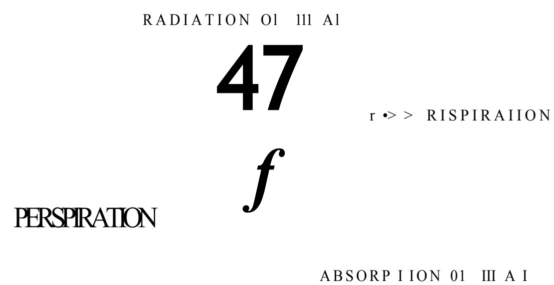


Fig 2.7 The body gains and releases heat and moisture from the surrounding environment to maintain thermal balance

? What is the relative humidity of the indoor air?

? Are there any air currents?

? How many other people in the same area are performing similar or different activities?

For example, a person playing an indoor sport might welcome a breeze to cool the body of excess heat, whereas a sedentary person might feel chilled by the same breeze as it is carrying away heat needed to stay warm (figure 2.8). Similarly, a person wearing several layers of winter clothing while indoors might feel uncomfortably warm while a person in a light sweater will feel very comfortable. In short, "the human body is not comfortable when it is placed under thermal stress" (Allen 1995:17). Comfort therefore can be described as "the feeling of thermal balance", where there is a neutrality between the amount of heat generated by the body and the amount that leaves the skin. (Olgyay 1963:15). Although the body does have mechanisms to deal with thermal discomfort, such as shivering to increase the body's metabolic rate and stay warm (figure 2.9), the ideal interior environment will be one where the occupants have thermal balance.

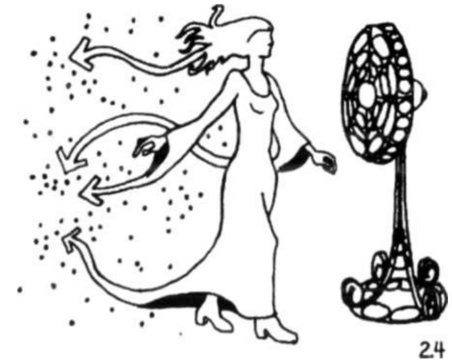


Fig 2.8 A breeze can remove heat from the body making you feel cool or cold

Fig **2.9** Shivering is the body's way of increasing the amount of heat it generates to warm the body

Although there are examples of rigorous scientific methods for establishing the human comfort zone (such as Olgyay's Bioclimatic Comfort Chart [Olgyay 1960:17]), simple air temperature regulation is the most commonly used index of comfort. As a result, most modern North American buildings are designed to operate within the limited range of 22-24° C, this being the established average comfortable temperature for North American occupants. It is important to note that this standard, although attempts have been made to universally apply it to cold climate buildings, is based upon levels of comfort for the average *westernized* North American person. In other climates or in different societies, such as the Inuit of the Canadian Arctic who live in a consistently cold climate and would have adapted to colder climatic conditions, indoor temperatures in the 22-24°C range are simply too warm and create a condition of thermal un-comfort. Although temperature can successfully be used as a marker of human thermal comfort, it is imperative that individual, cultural and climatic differences be considered as they can also influence human comfort.

2.1.3 THE BUILDING ENVELOPE

The building envelope is the system that creates an interior environment separate from the exterior environment (figure 2.10). It provides a barrier between the indoor and outdoor environment and "is the main instrument for fulfilling the requirements of comfort ... [and] modifies the natural environment to approach optimum conditions of livability" (Olgyay 1963:15). But what is

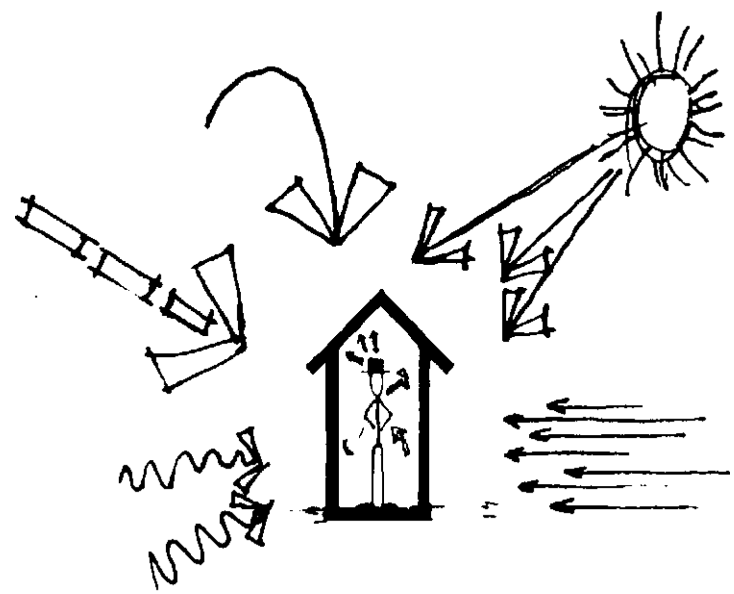


Fig 2.10 The building envelope serves to separate and regulate the indoor environment from the outdoor environment

the building envelope and how does it fulfill its role as a barrier to the outdoor environment?

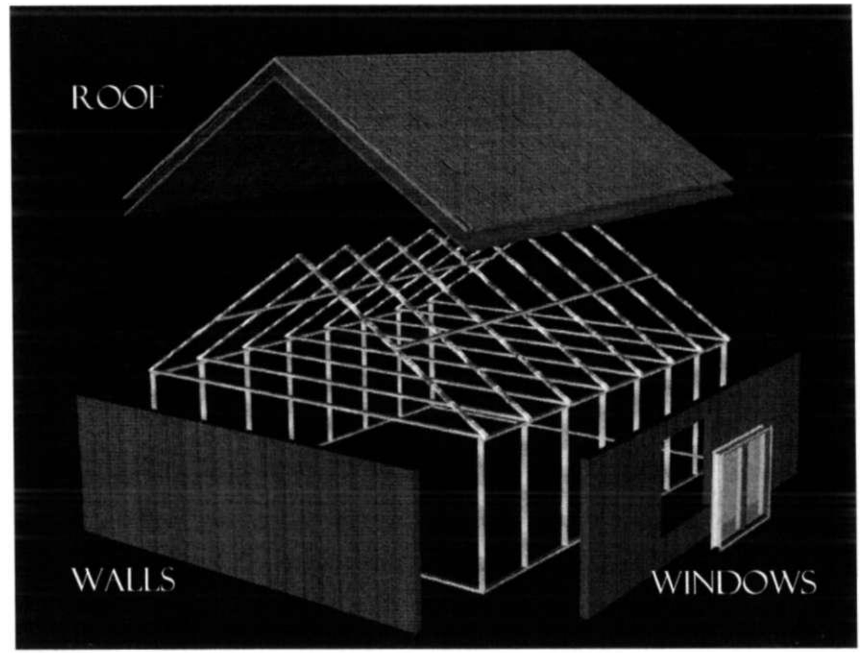


Fig 2.11 The building envelope is comprised of the roof and exterior walls, windows and doors

The building envelope, which is often now referred to as an *environmental separator,* is formally defined as "those [combined] parts of the building which separate inside conditioned space from unconditioned or outside space, such as windows, doors, walls, roofs and foundations" (CMHC 2000:glossary) (figure 2.11). Ton Alberts has more conceptually referred to the building envelope as a third skin: "We have our own skin, most of the time we put some clothes on as a second skin and our built environment can be seen as our third skin" (Alberts 1992:forward). The protective nature of the building envelope is essential to maintaining a comfortable indoor environment, separate and protected, from the outdoor climate.

Central to defining and understanding the building envelope has been the concept of the *interior* and *exterior* environments as two separate and distinct spaces. Thomas Markus and E. Morris, in their book Buildings, Climate and Energy (1980:23), suggest that such a rigorous distinction cannot be made. The previous definition of the building envelope, which includes immovable elements such as walls, foundations and roofs, also incorporates movable elements, such as windows and doors. Because of the operable nature of these latter elements, the building envelope is not a continuous barrier. Rather, "the building skin is acting as both a barrier and filter" (Reid 1998:39) (figure 2.12). The filter elements, while they serve to maintain the barrier, also allow controlled ventilation, daylight, access and communication with the external environment. Thus the building envelope is intended to create and control an indoor environment that allows for the select flow of light, air and communication.

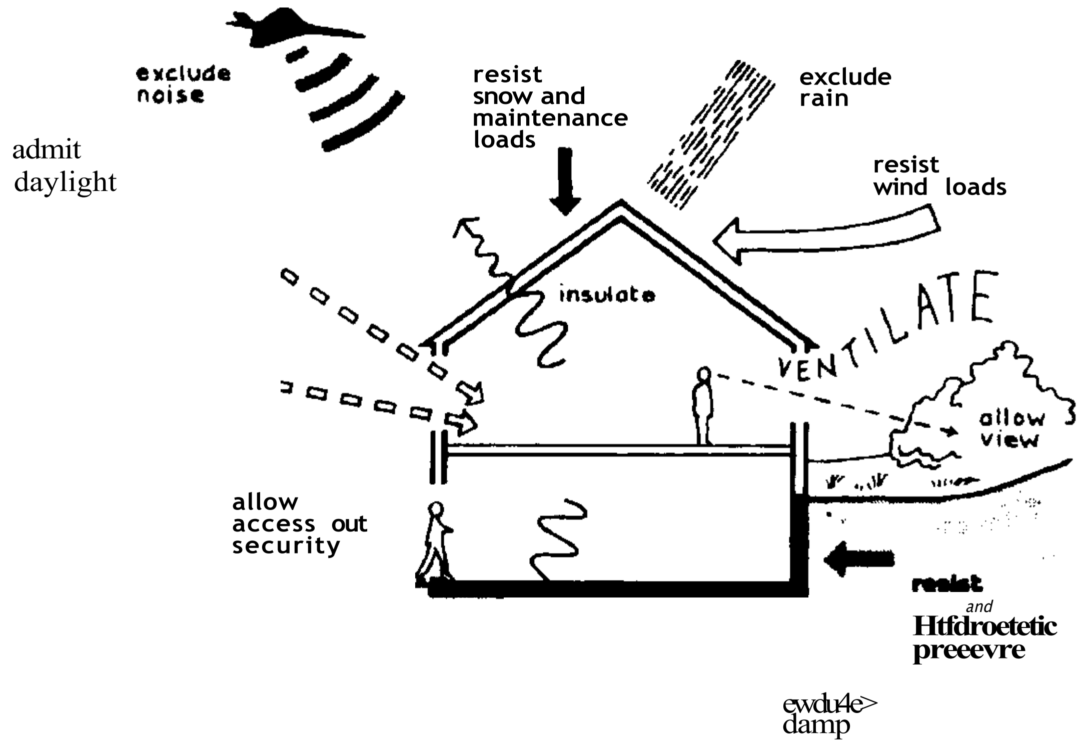


Fig 2.12 The building envelope acts as both barrier and filter

2.1.4 CLIMATE AND BUILDING FORM

In understanding the building as a mechanism for separating an internal environment from an external environment, it is only logical that the nature of the external environment (that from which people are trying to protect themselves) will influence the built form. Neil Hutcheon, former director of the Division of

Building Research at the National Research Council, agrees and states that "the differences in the properties of inside and outside atmospheres to be separated by a wall [will] dictate the requirements of that wall" (Hutcheon 1963:4). This is not a revolutionary concept, as it is well known that 2000 years ago, Vitruvius, a first century BC Roman architect and theorist, acknowledged the importance of climate to building form (Olgyay 1973:4). Figure 2.13 presents various examples of how each building form seems to respond to specific climates.

If we view the building's response to climate as the extent to which the envelope is either barrier or filter, this can illuminate how we conceive of the built form. The regional designs in figure 2.13 clearly illustrate how the nature of the envelope appears to respond to the different qualities of each climate. The cold climate has a compact building with few penetrations (filters) and a continuous envelope (barrier), to keep the harsh external climate out. Alternatively, the building in the hot and humid climate has more penetrations (filters) and less of an envelope (barrier). In fact, walls are not even necessary, as even a filter can be too much of a barrier in a hot climate. In short, "buildings are made to respond to the demands of the particular climate to which they are subject" (Oliver 1987:128). If the climate is more or less demanding,

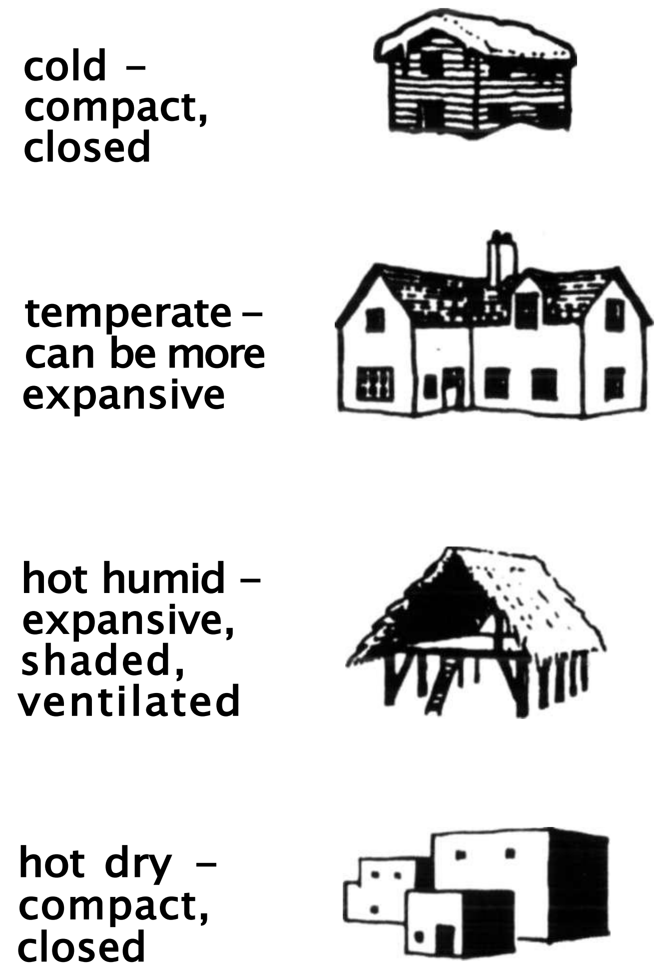


Fig 2.13 Building form often reflects the various requirements of climate

then the design will likely reflect the occupants need for barriers and filters in the building envelope.

What is essential to realise is that a building with an envelope does not have to be equipped with four walls and a roof. The example, in figure 2.13, of hot and humid construction clearly illustrates this point, as the building is comprised of only four posts and a roof. Figure 2.14 reinforces this point, as each building will provide shelter, to a greater or lesser extent, from the exterior environment. In certain instances, the filter elements will be necessary to cope with climate, while in others, the barrier elements are essential to survival. The universal feature shared by all forms of shelter is to separate occupants from the external environment.

It is important to note that, although buildings must naturally respond to climate, "from early time, a building was also required to give an established place of social and religious identity" (Osbourn 1985:2). This is evident in cultures from around the world, from the past and present, whose religious and sacred architecture still stands as testament to their worship. Therefore, while climate does play an integral, and often determining role in influencing the design of a building, there are many other cultural factors that influence design.

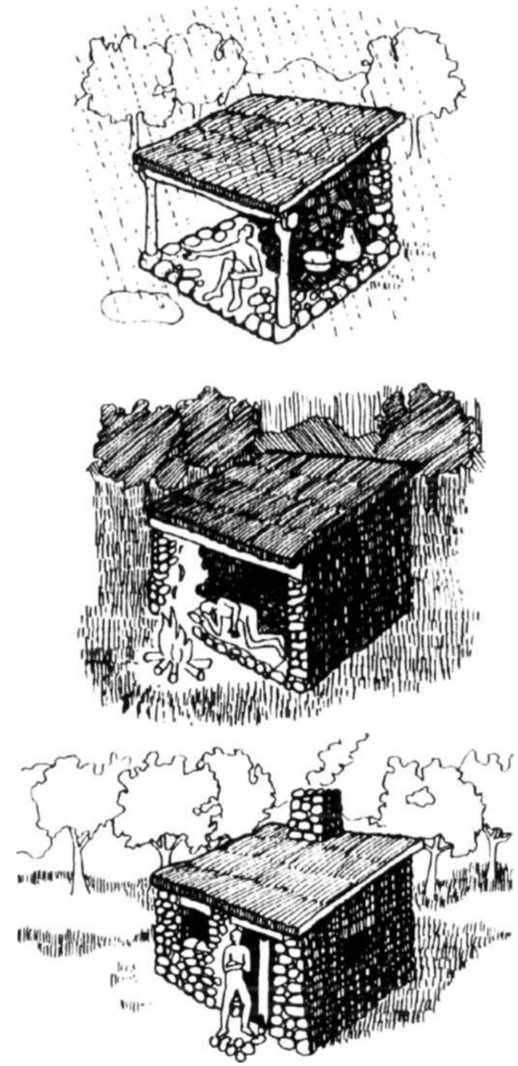


Fig 2.14 All three buildings provide shelter, to a greater or lesser extent, from the exterior environment

2.2 W1 IAT DO WE BUILD?

This section will address two main issues: the evolution of the use of buildings, and the definition of buildings and other forms in the built environment.

2.2.1 THE EVOLUTION OF USE

What do we build? Upon initial inspection, it may seem ridiculous to speculate on such an obvious question. The answer of course is that we build buildings. As Brand (1995:2) notes, the answer is intuitive in the very word *building:* "It means both 'the action of the verb BUILD' and 'that which is built' - both verb and noun, both the action and the result." This act of building, and the buildings that are produced, has in the past been perceived as a powerful catalyst to cultural development. Viollet-Le-Duc (1876), for example, begins his historic book with man evolving from "uncivilized" to "civilized" through the process of building and inhabiting buildings (figure 2.15).

Fig 2.15 Viollet le Due's civilization of man facilitated by the beginning of construction and inhabitation of shelter

Many philosophers, thinkers and writers of architecture, including Le Corbusier, have similarly pondered the evolution of man and the built form (Vogt 1998). Based upon these writings, the birth of conscious building is deemed to be a seminal event, where man makes an informed decision to construct a shelter to protect himself from the environment, rather than cowering in the landscape (figure 2.16). This construction then evolved through the predictable stages of increased closure and security, thereby allowing more and more of the daily activities to occur within the building. The expectations of the occupants also evolved and became more elaborate, for what was "initially providing a good standard of comfort and convenience, eventually became substandard accommodation" (Osbourn 1985:2). This process theoretically continued through time (with the assumption that progress was made through time) to arrive at what we know as modern building.

Fig 2.16 The first shelter built by man according to Viollet le Due

Our contemporary expectations of modern buildings can succinctly be summarized in the following statements:

> We have grown to expect more and more of our buildings, to the point that buildings now are expected to perform functions that are not strictly 'sheltering' at all, such as providing water, removing wastes and furnishing energy for use in mechanical tools (Allen 1995.23-24).
>
> Our modern buildings are in fact expected to be life support machine(s) (Osbourn 1985:2).

These statements illustrate not only the changes in occupant expectations of their building, but also reflect the advances in technology that have facilitated these expectations. Modern heating and cooling, plumbing and provision of fresh water, lighting and entertainment, all embody today's comprehensive building. These requirements have garnered such an important position in society, that even the plumber has been raised to a position of status. This can be seen in the edited compilation Plumbing: Sounding Modern Architecture (Lahiji and Friedman 1997) where various authors extol the virtues and indispensability of the plumber to modern society.

With the concept of the building in mind, it is imperative to discuss why there appears to be different categories of the built form, such as architecture, buildings, shelter, dwellings and enclosure. Interestingly, neither the Penguin Dictionary of Architecture (Fleming et al 1991) nor the Dictionary of Architectural Science (Cowan 1973) contained definitions of any of the aforementioned words. Are we to presume that they are synonyms, incarnations of the same thing, as each are built and inhabit a place within the built environment?

2.2.2 SHELTER: THE ETERNAL ARCHETYPE

An investigation of the language of the built environment reveals that a significant body of scholarship has pondered this very topic. For example, Roger Connah's recent compilation Welcome to The Hotel Architecture (1998) is an entire compendium discussing the use of the language of the built environment. A point of origin for this discussion can be found, however, in the "Primitive Building" which stands as the eternal archetype of building construction (Oliver 1969:9). It is the quintessential building from which all other later buildings have been derived. However, what can be classified as a "primitive building?" Was it originally a shelter? A building? A piece of architecture? A simple structure? All of these definitions could be correct. However, each individual term can be variously defined and often implies very specific social and societal meanings.

For example, shelter has been variously defined as protection against the weather and environment, and often has associations with the rudimentary and the temporary. The term building is generally used in a generic context for anything that is built, and often "indicates a lack of quality" (Oliver 1969:12). Architecture, on the other hand is often defined as:

- buildings designed with a view to aesthetic appeal (Oliver 1969:9)
- monumental and ornamental shelter (Markus and Morris 1980:12)
- shelter plus (Holdsworth and Sealey 1992:22)
- permanence (Brand 1995:2)

While the terms shelter and building can be used generically, and often associated with substandard connotations, architecture customarily refers to those buildings of a higher standard of design, construction and social meaning. This is exemplified in Banister Fletcher's seminal tome on the History of Architecture

(1987) where only an insignificant portion of the book is dedicated to buildings that do not meet all of the criteria outlined above.

In relation to one another, these definitions imply a hierarchy, where architecture remains a sophisticated manifestation of building, and building implies a developed incarnation of shelter. As such, shelter seems to be the most fundamental form of construction, encapsulating everything embodied in building and architecture (figure 2.17).

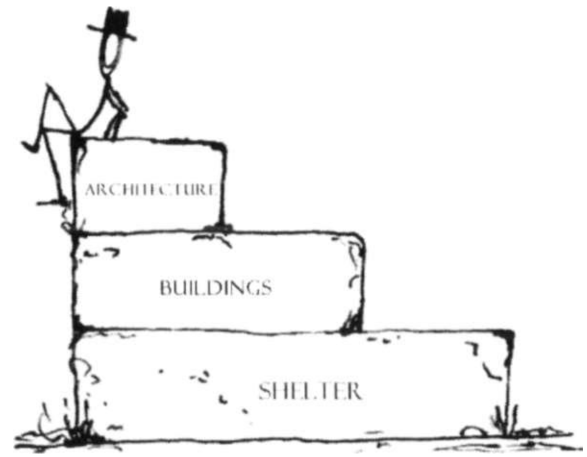


Fig 2.17 The hierarchy of built structures illustrates that at a fundamental level, examples of architecture and buildings are all forms of shelter

In looking to the *beginning* (Viollet Le Due and Corbusier) where shelter is perceived as the inaugural attempt at construction, we see "the basic desire for protective... [conditions]...is common to most, if not all, peoples of the earth" (Oliver 1987:7). This is easily and expediently achieved as outdoor conditions can be

> modified by the simple presence of the built form. Once there is a building, or even a garden wall, it has an exposed face and a sheltered face, and the spaces around the building are then subject to a new climate (Holdsworth and Sealey 1995:24-25).

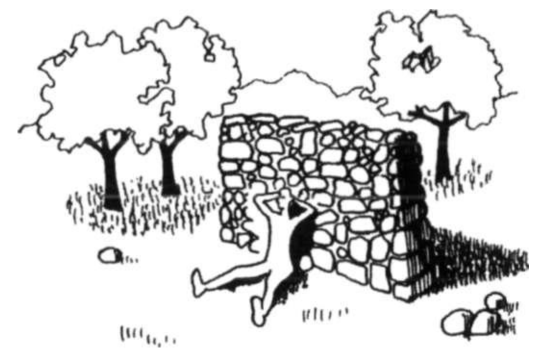


Fig 2.18 A microclimate is created simply by sitting on the sunny side of a wall. The wall thereby provides shelter to the person

A shelter can be as simple as creating a micro-climate (figure 2.18) that meets the occupant's needs for comfort, well being and security, or as grandiose as a palace, that at its base level, will perform the same functions.

2.2.3 SHELTER THROUGH TIME AND SPACE

History books of architecture, buildings or shelters often focus on one specific time period or one particular country or geographical location. When all of this information however, is compiled in relation to one another, it quickly becomes obvious that "we are in the presence of a system continuous in space and time" (Markus and Morris 1980:16). Archaeology has confirmed that early evidence of shelter is not limited to specific areas often referred to as the cradles of civilization such as Egypt, the Indus Valley or Sumeria (modern day Iran and Iraq). Rather, this phenomenon appears to be a universal trend that has extended through time. While this fact is not often acknowledged, it can be intuitively understood, as all people need shelter from the external environment

2.3 THE NEED FOR. A HOLISTIC APPROACH TO BUILDING ANALYSIS

Buildings, in whatever form they are manifest, are comprised of individual elements, components and systems that make up the whole. As technology has progressed so has specialization in each aspect. The result has been the loss of perspective due to a focus centered almost entirely on individual elements, rather than the building as a whole.

2.3.1 CURRENT DISCIPLINE

Buildings go through a multitude of stages during their life-span. They are designed, built, occupied, renovated and demolished. On initial inspection, these phases of a building's life are often associated with modern buildings. Similarly, the industries linked with these phases of construction, such as architecture and engineering, are often perceived as part of a modern context. In fact, all buildings, from the past and the present, will experience these same phases, and while there are the industries commonly associated with constructing new, modern buildings, there is also a suite of other disciplines that study a building's life, both from the past or the present. For example, academic disciplines such as archaeology will excavate and study buildings; anthropology will examine the impact that buildings have on society, art and architectural history will contemplate the design and style of buildings; craftsmen and tradespeople will restore old buildings and detail new ones. All of these disciplines, including the architect and the engineer, might study buildings from either the past or the present (figure 2.19).

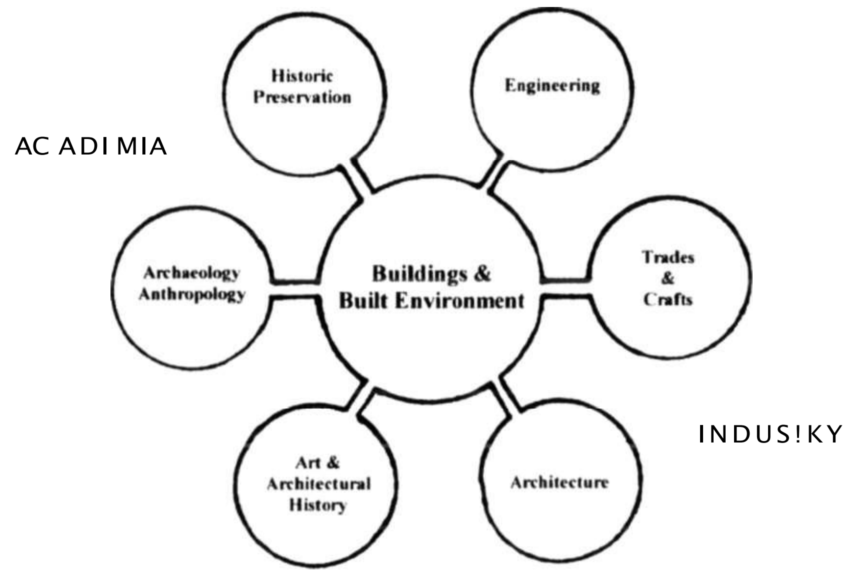


Fig **2.19** There are many disciplines that are part of both industry and academia that are affiliated with buildings and the built environment, from the both past and the present

Building research in any of these above disciplines is commonly performed in one of two general ways:

1. the investigation of individual construction components such as walls or windows or specific materials like wood or concrete

2. the examination of different construction phases or historic time periods.

In the first instance, intense marketing and research has focussed on construction components and materials. In fact entire industries have been developed that focus on one specific building component. For example, "this company" is one of many companies listed in the SWEETS catalogue that develops and sells wall systems (figure 2.20). Many other companies specialise only in window systems, doors, roofs or individual materials. The Canadian Wood Council is an example of an organization that promotes the use of only wood construction products. Individual companies further specialise, manufacture and sell only one wood product such as wood studs. Similarly, an academic discipline such as archaeology can study individual materials such as stone, or individual building components such as wall construction.

Fig 2.20 The EIFS system is just one of hundreds of wall systems available in todav's market

In reference to the second style of building research, academic disciplines, such as architectural history or archaeology, focus heavily on one historic time period associated with a distinct design style, such as the Gothic Period or the Greek

Revival. Likewise, one specific construction phase is often a point of intense examination.

The result of such intense specialization is that industry and academic disciplines affiliated with the building industry are highly fragmented in nature (figure 2.21). This is apparent not only in the construction of new buildings, but is also prominent in the renovation, investigation and research of buildings from the past. This specialization has resulted in the growth of specialists in many areas such as materials or construction styles. This has lead to further fragmentation of the industry where, as Elder et al (1974:10) explains, "... a complex problem is divided into separate strands and each is tackled individually, probably by different specialists or specialist teams." The result is that the knowledge of buildings and the build environment is comprised of specialized industries and academic disciplines, managed by specialized people, and buildings are designed, built and researched in a fragmented way.

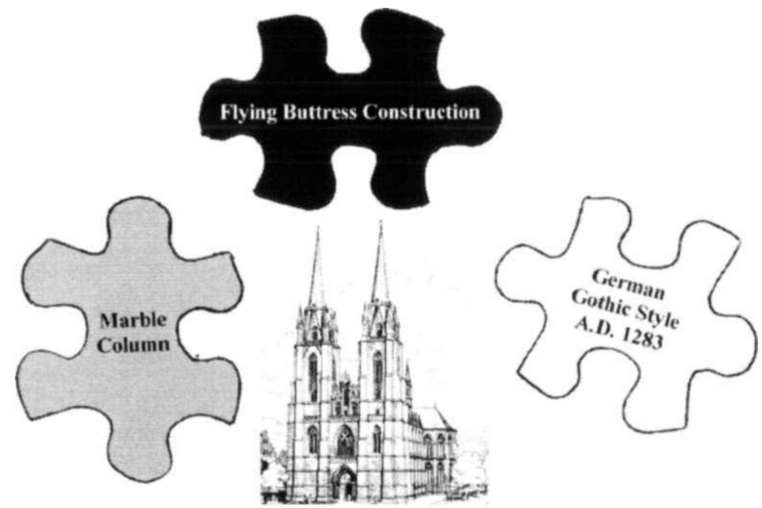


Fig 2.21 An understanding of a building, such as the Church of St. Elizabeth in Marburg, Germany, is often fragmented, as information is gleaned from disparate disciplines

2.3.2 WHY DO WE NEED A HOLISTIC APPROACH?

There is no doubt that specialization has been very successful. Advances in modem lighting equipment and heating and cooling equipment for example, have attained standards of performance that were undreamed of in the past. While Elder et al in the AJ Handbook of Building Enclosure agree that specialization has nurtured and advanced the technology of buildings, they are concerned that this fragmentation has compromised the integrity of the building as a whole.

> The problem is a lack of overall control and integration; the subsystems dominate the total system, are inconsistent with each other and occasionally even counteract one another
> (Elder et al 1974:52).

Although this comment was published over twenty five years ago, the statement holds true as the fragmented condition in the industry still exits. In fact, it has become exacerbated by the increasingly specialised technology of individual materials, components, systems and buildings. Not surprisingly, a holistic view of the building has been largely neglected, and the intrinsic concept that the building is an entity unto itself appears to have been abandoned by modern building industry and research.

Perhaps the most salient concept that necessitates the rejection of a fragmented approach to the built form is that buildings are composed of numerous elements that are part of a greater whole and any alteration in one will naturally affect the greater building system. Edward Allen (1995:29), in his book How Buildings Work, states that "a building has its own ecology, a delicate internal balance of connected mechanisms that function not in isolation but as a richly interconnected whole.*' The corollary is that one element cannot be analyzed, installed or changed without implications to the whole building. Like the human body, where a foot cannot exist without a leg, so too in a building a door cannot exist without a frame or a wall (figure 2.22). Likewise, a roof is meaningless without something beneath it to protect.

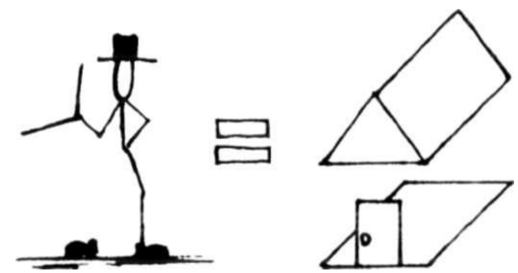


Fig 2.22 Like the human body, where a foot cannot exist without a leg, so too in a building, a roof is meaningless without something beneath it to protect

In short, few functions of the building occur in isolation. While there is no doubt that specialization has benefited the construction industry and occupant comfort, an increased focus must occur specifically on the building itself. Joseph Lstiburek (1998), an engineering consultant with the Building Science Corporation stresses that many modern buildings lack longevity, not because of shoddy materials or components, but due to the lack of understanding of the building as a system A paradigm shift must occur towards a more holistic practice where, in conjunction with the current practice of intense specialisation, a complete understanding of the building can be achieved.

2.3.3 BUILDING SCIENCE THE HOLISTIC DISCIPLINE

By changing our view of the building to encompass a holistic perspective, the building industries must also alter their orientation and praxis. The common body of knowledge for building technology and research that presently exists as a fragmented compilation of information, must be consolidated through one discipline: building science.

Central to the discipline of building science is the building envelope. The building envelope is the system that creates an interior environment separate from the exterior environment. The interrelationship between the elements that comprise the building envelope (materials, components and systems) is known as building science. This discipline does not solely look at individual materials or components of the envelope. Rather it strives to investigate and understand the interrelationship between the elements and how these elements come together to make a building (figure 2.23). Unlike the fragmented trends in the building industry, it is only when

> the total system is evaluated, and never isolated subsystems, [that] the optimization is of the inter-relation of the subsystems rather that the subsystems themselves (Chahroudi & Wellesley-Miller 1975:157).

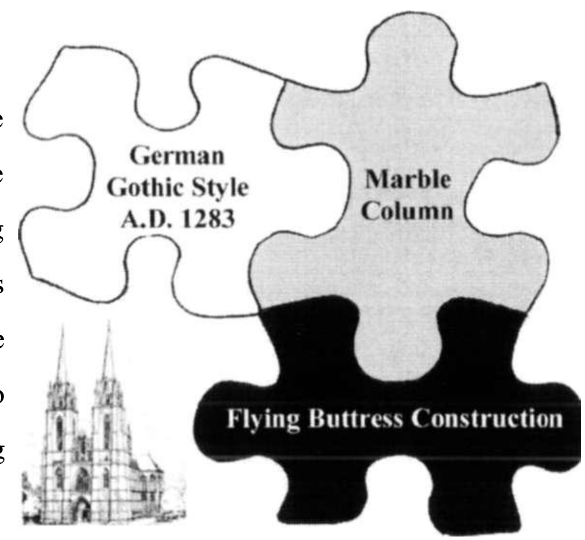


Fig 2.23 Building science facilitates understanding the building as whole, and tie the disparate parts of the building industry and academia together

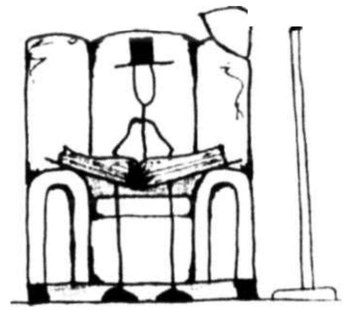
Building science will view and understand buildings from a holistic perspective and has the potential to tie the disparate parts of the building industry and academia together. Furthermore, it has the capability to span any distinct profession that utilizes the building as its focal point for research. Currently the many disciplines that centre on buildings, such as architecture, engineering, historical preservation and archaeology, are perceived as separate, unrelated entities. Building science, by providing information about buildings, can bring them together to create a dynamic awareness of the construction, habitation and life cycle of buildings.

2.4 SUMMAHY

Buildings are an omnipresent part of our lives. The need for their sheltering function is universal and is exhibited in all forms of building. The exterior environment is often harsh, and the building envelope strives to create a more hospitable interior environment, suitable to the occupants needs and requirements for comfort. While there are many academic and industry disciplines that are related to buildings, there has developed an intense specialization that has resulted in a fragmented understanding of most buildings. Building science can provide a holistic understanding of buildings, from both the past and the present, that will facilitate not only an awareness between disciplines, but more importantly, a comprehensive understanding of the built environment.

CHAPTER 3: THEORY

WHAT IS BUILDING SCIENCE?



3.1 INTRODUCTION

Every building has a building envelope, the system that creates an interior environment separate from the exterior environment. The interrelationship between the elements that comprise the building envelope (materials, components and systems) is known as building science. It allows the individual to gain insight on broad-level issues such as thermal performance, as well as delve into specific and localized topics such as the relation of a wall to a ceiling, or the role of wood versus steel in framing construction. It is both a tool, and a point of view, that academic and industry disciplines, such as archaeology and architecture, which work with the built environment can use to address a wide array of issues.

Because of its broad applicability, building science is a powerful tool for analysing and designing buildings in a modern context. Since buildings have existed, in one form or another, for millennia, the question we need to ask is can building science be used to analyze any building, from any geographical location, from any time period? The aim of this thesis is to show that it is possible to apply building science outside of the modern context and more fully understand the built environment in which we live (figure 3.1).

Thesis Objective

TO ILLUSTRATE HOW BUILDING SCIENCE IS INTEGRAL TO INTERDISCIPLINARY EXAMINATIONS OF BUILDINGS BEFORE THEY ARE BUILT, WHILE THEY ARE STANDING AND AFTER THEY HAVE FALLEN DOWN.

Fig 3.1 Thesis objective

In order to fully understand how building science as a discipline can be used to analyse buildings from any geographical location and from any time period, we must have an understanding of the discipline itself. To do this, it is important not only to examine building science, but it is essential to explore the discipline at its most basic level, at the foundation of its fundamental ideas. To make building science universal so that it can be used to analyze any building, we must investigate and understand the discipline at a level common to *all* buildings, from the past and the present. For example, it would not be worthy to discuss how building science can inform an investigation of glass windows, when many buildings do not (or did not) have them. By emphasizing the skeletal framework of the discipline we can derive logic and understanding from principles so basic that all further structures/buildings should be derived from them (figure 3.2). In this way, a building that was built yesterday can be analyzed in the same way as a building from a thousand years ago.

Theory Rationale

TO DERIVE LOGIC AND UNDERSTANDING FROM PRINCIPLES SO BASIC THAT ALL FURTHER STRUCTURES / BUILDINGS SHOULD BE DERIVED FROM THEM

Fig 3.2 Project rationale

This chapter will investigate the rudimentary framework of building science, which is comprised of three component parts: the physical elements of a building, the principles of materials and components and the functional requirements of every building. A comprehension of each of these three areas and of their interrelationship comprises the essence of building science. Finally, the spheres of influence, those geographical and cultural strata that make buildings different from one another, will be discussed.

3.2 PHYSICAL ELEMENTS OF A BUILDING

The physical elements are those material aspects of the building that are the result of an intentional act of building. Every building will have these physical elements, as they are the essential components of every building.

3.2.1 SITE

Site is the area in which the building is located (figure 3.3). It is comprised of the local geographical features and the space around the building. Site is often perceived to extend various distances around the building, depending on the research viewpoint or project objectives. For example, a site might be a residential plot or it could be the block in which the plot sits. The site can extend anywhere from a few metres to a few hundred metres or more around the building. The building therefore occupies a piece of real estate, and is impacted by and impacts the site and its environment.

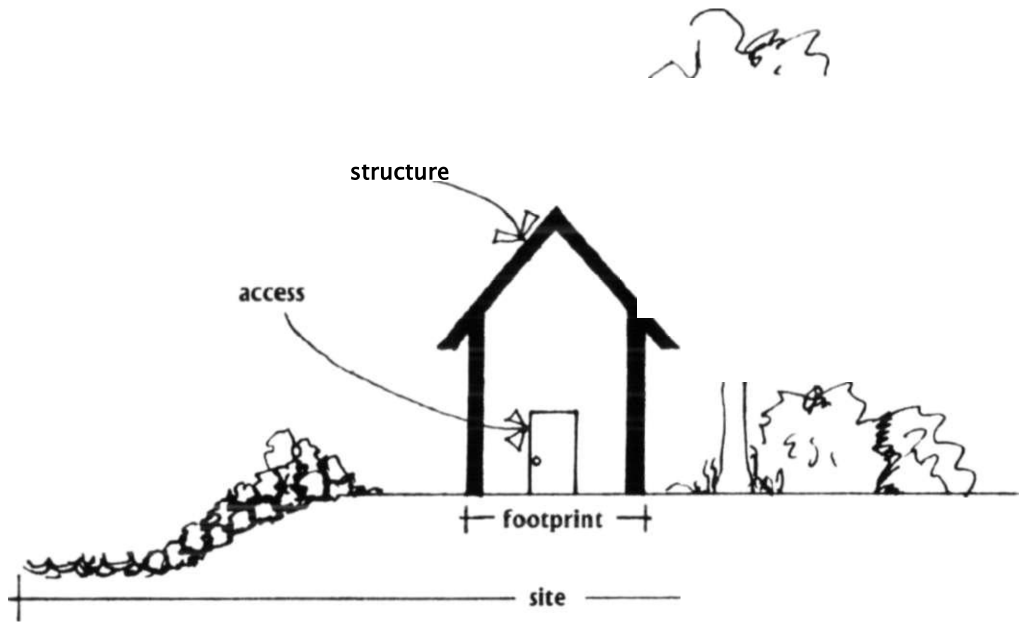


Fig 3.3 The physical elements common to all buildings through time and geographical location

3.2.2 FOOTPRINT

A building's footprint is the area of ground on which the building physically stands (figure 3.3). When the building itself does not physically touch the ground, the footprint is defined as the area where the support of the building interfaces with the earth. For example, a building on stilts would have a footprint of the four poles (figure 3.4), while a treehouse would have a footprint of the tree base.

3.2.3 ACCESS

Every building must have a point of access, or a point of entering the building, whether it is from below, above or the side. There must, out of necessity, be at least one point of access on every building (figure 3.3)

Fig 3.4
Even a building that is not built on the ground will have a footprint

3.2.4 STRUCTURE

An intuitive aspect of any building is that it is constructed for the purpose of protecting its occupants. It is therefore essential that the building maintain its form (however that is defined) and have structure to keep it from falling down. Structure is defined as the combination of units interconnected in accordance with a design and intended to support loading (dynamic and static) or forces from any direction (vertical and horizontal) (figure 3.3). Examples of vertical loading are gravity or snow build-up on a rooftop, while horizontal loading would be a force such as wind. Buildings must have structure to withstand these forces in order to remain standing.

3.2.5 SEPARATION

The basic function of a building (as discussed in Chapter 2) is to provide protection from the exterior environment. The mechanism by which the building satisfactorily establishes an "interior" from an "exterior" is known as the building enclosure, or the separation. Although in many instances there is a physical separation, there are also examples where the protection achieved by the building is accomplished by way of a perceived separation. For example, in figure 3.5, the building, which many would say is a grass hut, satisfactorily protects the occupants from the sun and rain. This constitutes the separation that is required by the

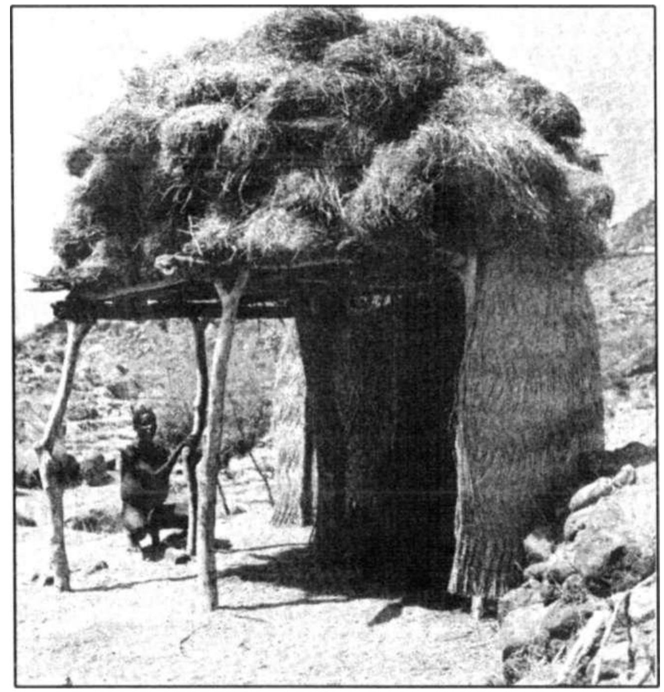


Fig 3.5 Even though there are no walls, this building still has separation from the exterior environment

occupants. Although the building envelope is not continuous (i.e., four walls and a roof), it still functions to separate and protect the occupants from the exterior environment. This separation will occur to a greater or lesser extent in every building.

3.3 PRINCIPLES OF MATERIALS, COMPONENTS AND SYSTEMS IN THE BUILDING

The fundamental principles that influence the materials, components and systems of a building have changed little over time. These laws of physics are applicable to buildings and materials from both the past and the present, and are essential in understanding the nature of any building envelope.

The following list includes the main principles that apply to building science:

1. Forces exist to achieve balance
2. There is always a point of diminishing return
3. Heat travels to the colder side
4. The greater the difference in temperature, the greater the heat transfer
5. Heat transfer by conduction will always occur
6. Materials will not deteriorate if one of the conditions for deterioration is absent
7. Materials must have sufficient time to cure under optimal conditions
8. Moisture can change the properties of materials
9. Materials change dimension with temperature change

10. The weakest material will fail first
11. No material is infinitely strong
(based upon Lee 1997: lecture)

Although there are undoubtedly many other principles pertaining to materials, components and systems of a building, those not listed here are either not immediately pertinent to building science or they can be distilled to one or more of the principles below. The principles are not meant to be read, understood and used in isolation. Rather they are meant to be fluid and interrelated. Finally, in the description of each principle, only examples from modern construction have been used, to facilitate understanding and simplify examples.

3.3.1. FORCES EXIST TO ACHIEVE BALANCE

If there are two tanks sitting beside one another and they are connected at the bottom with an open pipe, and only one of the tanks is filled with water, they will both end up containing equal amounts of water. This is because water will always strive to achieve a balance or equilibrium. In any instance, if water is adjacent to a space that has no water, it will attempt to find any fault in the separation to flow to the other space. For a building, water on the outside of a foundation wall will create a large amount of pressure as it attempts to equalize with the basement space of the building that has no water. This will create hydrostatic pressure that will find any imperfection in the foundation to infiltrate the basement.

Similarly, air pressure caused by wind around a building can have drastic effects as it attempts to achieve a balance. As with the example of water, the inside of the building is an artificial environment. A force, such as air pressure from the wind, will build up and attempt to equalize with the inside of the building because it is at a lower pressure. The result is stack effect (figure 3.6) inside a building where air rushes in the bottom of a building, forcing air out the top. As there is a greater difference between the interior environment and the exterior environment, so will there be a stronger force to achieve a balance and equilibrium

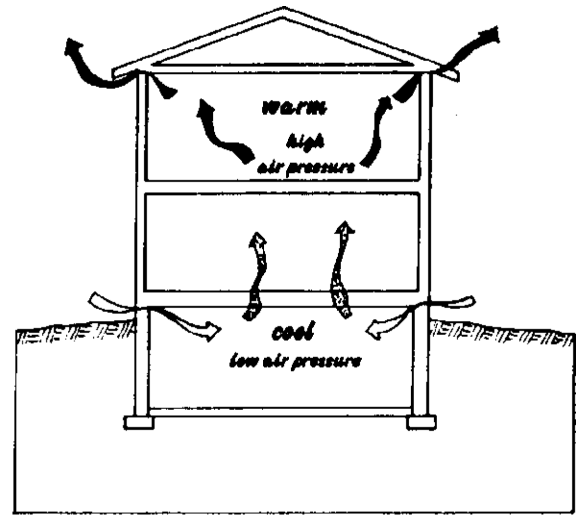


Fig 3.6 Stack effect is the result of air pressure attempting to achieve a balance on either side of the building envelope

Other forces that will affect the building envelope as they strive to achieve balance are temperature, sound, light and humidity. It is essential for a building to be designed and built to cope with these forces, as they will always attempt to achieve a balance between the interior and the exterior of the envelope.

3.3.2. THERE IS ALWAYS A POINT OF DIMINISHING RETURN

You have to use your muscles to hold a box. If you hold a heavier box, then you will naturally need to have stronger muscles. Larger muscles however, weigh more and you will need to have bigger bones to carry the muscles that are needed to carry the bigger box (figure 3.7). Similarly, in a building, a beam will span a certain distance, and there must be the required structure below to support that beam. If the same beam was designed to span a longer distance, then it would

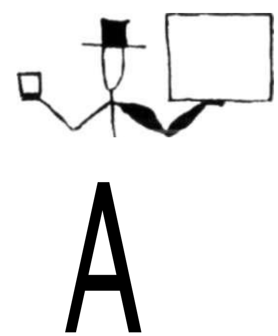


Fig 3.7 You need larger and stronger muscles to carry a bigger box. Similarly, a building will need a more robust structure to carry a larger load

have to be bigger, and as a result the structure below would have to be greater to support the additional weight. There is however a point of diminishing return, where the cost and efficiency of the supporting structure, and the space that it occupies, outweighs the benefits of having a larger spanned space.

A further scenario can be cited in window technology. The dead air space between the glazing of a double glazed sealed window unit acts as an insulating layer and the optimum gap is approximately 20 mm. There is a point of diminishing return where the thermal efficiency of the air space actually decreases if the space gets larger than 20 mm, since convection currents will develop between the glass panes. Similarly, there is a practical limit to wall cavity insulation. The first centimetre of insulation is the most effective. Each subsequent centimetre of insulation that is installed will be less and less effective. Therefore, although increasing the amount of insulation will slow the migration of heat through a wall, there is a point where the cost of insulation and materials to construct a wall to hold the insulation, will outweigh the cost of energy savings (figure 3.8). There is a limit to the efficiency of every material, and in every situation there is always a point of diminishing return.

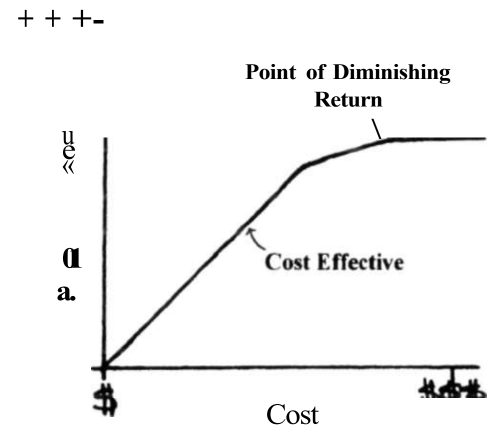


Fig 3.8 There is always a point of diminishing return with any design decision, where the amount of money invested will outweigh the returns

3.3.3. HEAT TRAVELS TO THE COLDER SIDE

Protection from the environment involves the creation and maintenance of thermal comfort for occupants. In order to achieve this, it is essential to understand that "heat energy always tends to migrate in the direction of decreasing temperature" (Stephenson 1968:1) (figure 3.9). In other words, heat travels from the hot to the cold. This principle appears to be such a well known fact that both Hutcheon and Handegord (1983) and Elder et al (1974) do not even mention or discuss the principle before they launch into the intricacies of heat transfer calculations (even though the calculations themselves are based on this principle).

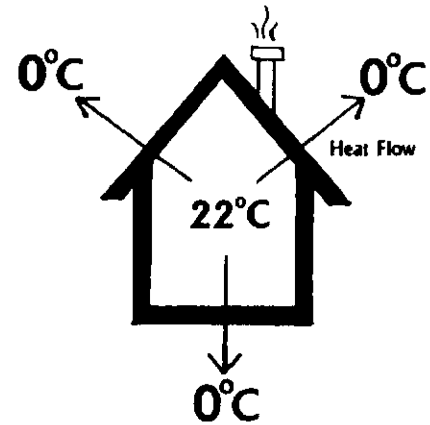


Fig 3.9 Because heat always travels to the cold side, the inside of the building will lose heat to the colder outside environment

Heat transfer is perhaps at the centre of most design issues in construction, both past and present. In maintaining thermal comfort in a cold climate, heating of the interior environment must be balanced with the amount of heat that will migrate to the colder outside. Alternatively, in a warm climate, the opposite will occur, where thermal comfort will be at the mercy of heat from the outside migrating inside the building (figure 3.10). Building design and material choices optimize conditions based on this principle and strive to use materials that will minimize heat flow from the hot to the cold to maintain thermal comfort.

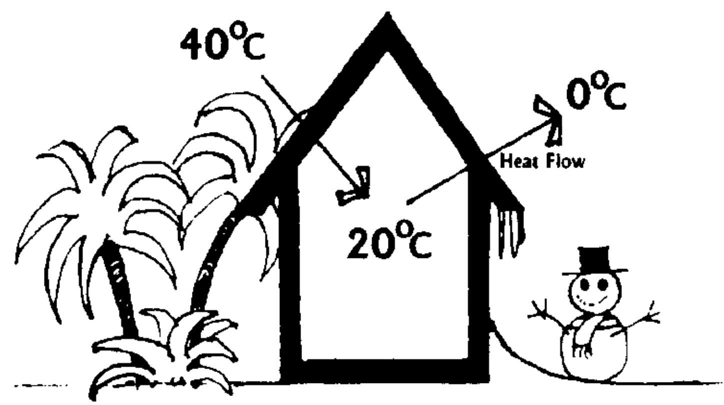


Fig 3.10 In a warm climate, heat will travel from the outside of the building to the inside, the opposite of a cold climate scenario

3.3.4. THE GREATER THE DIFFERENCE IN TEMPERATURE, THE GREATER THE HEAT TRANSFER

Seasonal weather patterns and daily extremes will constantly affect exterior environmental conditions. As a result, the difference between indoor and outdoor temperatures will fluctuate and rarely remain constant. This is particularly true of regions away from the equator that have marked seasonality. As these changes occur, and there is an increased difference between the interior and the exterior temperatures, heat will flow at an increased rate from the hot side to the cold side. As Newton's Law of Cooling states, "the rate of cooling of a hot body is directly proportional to the difference in temperature between the body and its surroundings" (Elliot 1977:85). Therefore, the greater the temperature difference, the greater the rate of heat transfer from hot to cold (figure 3.11). Regions with buildings that consistently have high temperature differences between indoor and outdoor conditions (in the polar regions for example) will naturally strive to have a more robust building envelope that will attempt to limit the increased heat transfer.

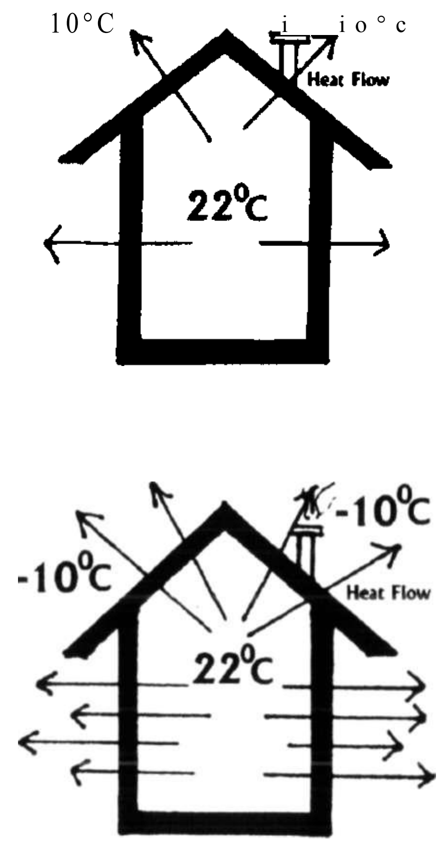


Fig 3.11 Heat will migrate to the colder side more quickly with a greater temperature differential

3.3.5. HEAT TRANSFER BY CONDUCTION WILL ALWAYS OCCUR

There are three methods whereby heat can be transferred:

> **Radiation:** the transfer of heat by means of the straight-line passage of electromagnetic waves through space or air from a warmer object to a cooler one (Allen 1995:47)

> **Conduction:** the transfer of heat through a solid material (Osbourn 1985:56)

> **Convection:** the transmission of heat by natural or forced motion of a liquid or gas (Cowan 1973.60)

Figure 3.12 illustrates each of the three heat transfer methods. While eliminating convection currents can halt heat loss by convection, and reflecting the heat back to the object of origin can easily stop radiation, conduction cannot be stopped and will always occur if there is a temperature difference. This is because every material, to a greater or lesser extent will transfer heat by conduction.

Because of the ever-presence of heat conduction, it is often considered to be the most important of the three heat transfer mechanisms in connection with building performance. Heat loss by conduction through the fabric of the building envelope cannot be stopped, and is often thought to constitute the largest portion of the heat loss from a building in a cold climate (Elliot 1977:86). Therefore, despite all attempts to create an indoor environment separate from the outdoor environment, the integrity of the interior is never completely protected from the outdoor environment.

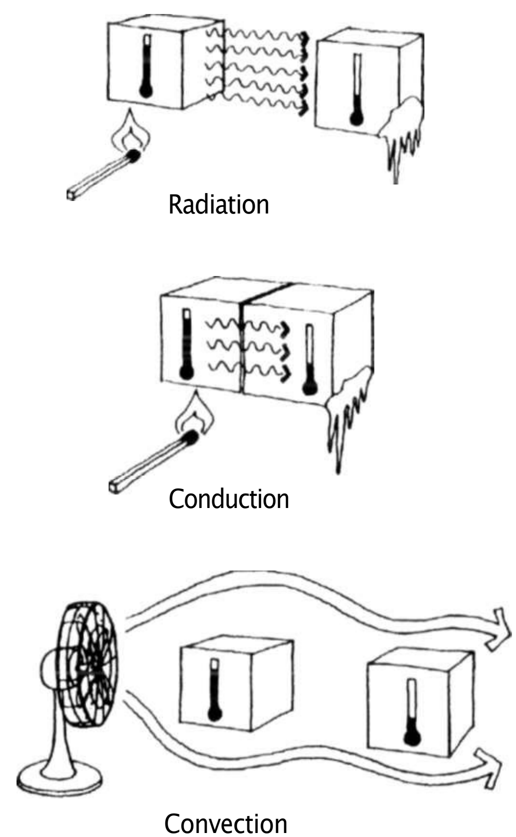


Fig 3.12 Three mechanisms of heat transfer that are important to the built environment

Although <u>every</u> material transfers heat by conduction, the rate that the conduction will occur is based upon the specific properties of the individual material. The coefficient of thermal conductivity, which is the measurement of heat loss by conduction, is a measure of how efficiently heat can pass through a material.

Therefore, a material with a high coefficient, such as steel, will conduct heat very well. These materials are very dense and composed of tightly packed molecules that are closely positioned and efficiently pass energy to one another. A material such as rigid insulation, on the other hand, has a low coefficient and is thus a poor conductor of heat. Less dense materials have very loosely packed molecules with a myriad of air pockets that break the material's continuity. As air is a poor conductor of heat and is perhaps the best resistor to conductive heat flow, porous materials are excellent insulators of conductive heat flow. The essence of material conductivity therefore, lies in the density of the materials. Glass fibre insulation does not conduct heat well and is therefore an excellent insulator. Although glass itself is an excellent conductor of heat, it has in this instance been blown into very fine strands. The result is a composition of fine strands of materials with large amounts of air between. As air is an excellent insulator, glass fibres spun into batts are excellent insulators. If the air pockets became filled with water (which is an excellent conductor of heat), the insulation value of the material would be significantly reduced. As discussed by Osbourn (1995:57), "a saturated material could permit about ten times more heat to be transferred through it when compared with its 'dry' state."

3.3.6. MATERIALS WILL NOT DETERIORATE IF ONE OF THE CONDITIONS FOR DETERIORATION IS ABSENT

There is a common misconception that water alone will deteriorate and destroy materials, components, systems and even entire buildings (figure 3.13). This fallacy stems from the belief that deterioration, such as metal corrosion or wood rot, are the result of water alone. Although this statement is correct in so far that if water is absent, deterioration would not occur, there are other conditions that *must* be present for the mechanism to begin. For example, in order for wood to rot (figure 3.14), *all* of the following specific conditions must be present:

- **Spores or source of infection:** Either mould or fungus spores are the essence of wood rot; spores are carried in the air and must be present on the wood,
- **Food source:** The spores require a food source, and the fibres of the wood are an excellent source of sustenance.
- **Air:** Oxygen is essential to the survival of the spores.
- **Optimum Temperature:** The spores must have a specific temperature range of 70-90°F in order to grow and multiply. They are extremely hearty however, and can withstand, while dormant, great temperature extremes.

Fig 3.13 It is a misconception that water alone destroys buildings

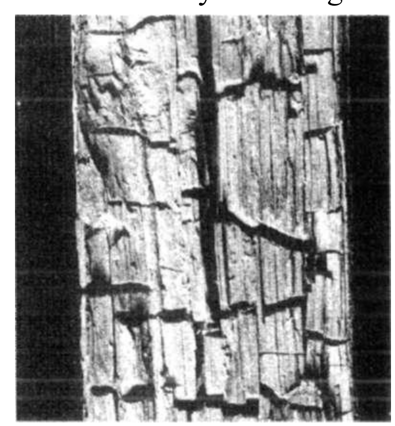


Fig 3.14 Wood rot can be destructive to buildings in any climate

S Water: Moisture is essential for the spores to thrive.

In normal circumstances, the first four conditions are usually present, and so it *appears* that the onset of wood rot corresponds with the addition of water (figure 3.15). However, there are instances where moisture is present and wood rot does not occur. In extreme cold climates the temperatures are too cold for spores to be active and grow. Alternatively, wood that is completely submerged in an anaerobic environment, such as water, will not decay, as there is a lack of essential oxygen.

Fig 3.15 Because most of the "ingredients" for wood rot are usually present, it often appears that water alone cause rot

Metal corrosion requires a comparable list of ingredients: oxygen, metal and water. In the absence of one of these criteria, corrosion will not occur. Interestingly, a specific temperature is not a prerequisite for corrosion, but it undoubtedly affects the process, as low temperatures will slow chemical deterioration. In fact, for every 10°C drop in temperature, the rate of chemical reaction is slowed by half (Strub 1996:46).

There are many types of deterioration that can be classified as cosmetic rather than chemical, but still necessitate the presence of specific criteria (including water!): spauling, blistering, efflorescence. Material deterioration can be summarised in the following statement by Latta:

> In many instances the water by itself is not harmful, and only when combined with other phenomena does it cause rapid deterioration. On the other hand, the other phenomena involved will not cause deterioration in the absence of water (Latta 1968:4)

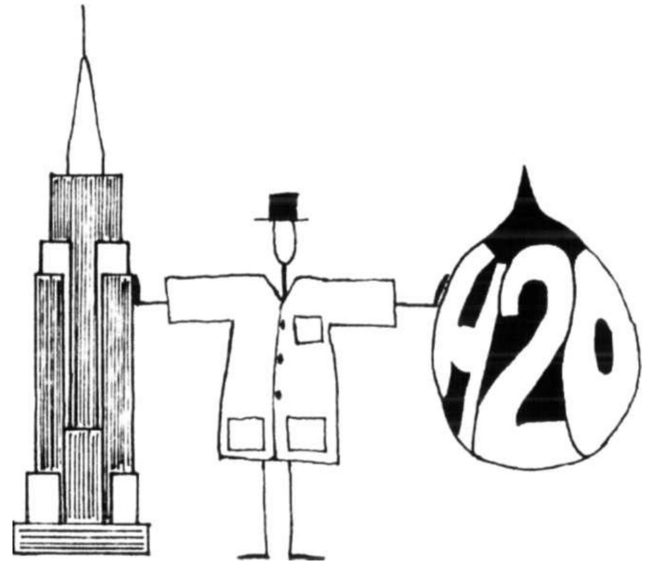


Fig **3.16** Water and buildings do not mix and every effort should be made to keep them apart

No building can last indefinitely. As the individual materials deteriorate and components change, the composite parts of a building render the building unsafe or unusable. Although the culprit to this deterioration is not water alone, ultimately water and buildings do not mix and every effort should be made to keep them apart (figure 3.16).

3.3.7. MATERIALS MUST HAVE SUFFICIENT TIME TO CURE UNDER OPTIMAL CONDITIONS

Very few materials are ready for use in a building directly out of nature and unprocessed. Most materials must be manufactured and prepared so that they are of a standard that can be used to construct a building. This includes the curing process, which is loosely defined as the period after manufacture where the material must either acclimatize or "set" before it is of an appropriate standard for use. The most obvious example of the curing process is concrete. Once mixed and poured, concrete must be allowed to cure. This involves an exothermic reaction where water is released from the material as it hardens. It is imperative that this process occur under optimal temperature conditions before it will attain its optimal strength. If the temperature is too warm, too much water from the concrete will evaporate leaving it too dry to cure properly and it will not achieve its optimal strength or durability. If the temperature is too cold, the water in the concrete might freeze causing spalling or unnecessary deterioration.

There are many materials that must cure in a similar way before they reach their optimum performance level such as paint, adhesives and sealants. However, there are other materials that must acclimatise, rather than set, before they are at their optimum performance level. For example, wood is often allowed to sit in a new building before use so that it can reach the same indoor conditions as the building. This is to ensure that the wood will not release much moisture once *in situ* and change shape. This is particularly important for lumber that is imported from different climates. Concern for material preparation and care are essential to maximize performance and endurance from building materials.

3.3.8. MOISTURE CAN CHANGE THE PROPERTIES OF MATERIALS

Water is perhaps the most powerful mechanism for change within the built environment. For many building materials in particular, the presence (or absence) of water can change their physical and dimensional properties and as a result have a detrimental effect on both the material itself and the building as a whole. Porous materials such as wood will swell if they absorb a significant amount of water. This swelling results in a decrease in strength of the unit and an increase in size. Alternatively, if a large amount of moisture is released from wood, the material will become stronger, but with the unfortunate side-effect that it could warp and crack. These dimensional and physical changes could have a detrimental effect on the building, if for instance a structural member is made of wood. Furthermore, if a component is comprised of wood in combination with other materials, differential changes in the materials due to moisture could be disastrous.

Sources of water and moisture are varied, but they can be loosely categorized into two groups: moisture originating outside the building, and moisture originating from within the building. Moisture originating within the building (figure 3.17) is generally the result of normal occupant activities such as cooking, bathing, clothes washing and drying, plant metabolism and occupant respiration. These activities can add a significant amount of moisture to indoor air. There are also non-occupant related mechanisms that will add moisture to the interior of a building. A dirt crawl space, for example, can contribute "as much as 40-50 litres of moisture per day [which] can be released by exposed soil" (Rousseau 1984:36). Similarly, new building materials often have a very high moisture content and will release that moisture to the indoor air. For example, as a concrete foundation cures, it can release 2,400 litres of water. Lumber used for construction at 19% moisture content can release a total of 200 litres of water as it dries to average

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Fig 3.17 A list of the main sources of water vapour in a dwelling, based upon a family of four

conditions (Rousseau 1984:35). This amount of water can significantly add to the moisture content of a building interior, affecting not only the materials that are releasing the moisture, but also those that are absorbing it.

Water sources from outside the building include rain, snow and rising moisture from the ground on which the building sits. These sources of moisture will affect the building's exterior, and if allowed, will penetrate the building envelope. Thus it is imperative in a modern building that the building envelope work to keep water out of the building and have mechanisms to cope with interior moisture generation.

3.3.9. MATERIALS CHANGE DIMENSION WITH TEMPERATURE CHANGE

An increase in temperature will result in an increase in dimension of most materials. The rate of dimensional increase per degree Celsius, for unrestrained material, is known as the coefficient of thermal expansion. For example, aluminum has a fairly high coefficient of thermal expansion (a 3 m length of aluminum with a temperature increase of 30°C will increase in length 2.2mm). Concrete has a lower coefficient of thermal expansion, as a 3 m length of concrete with a temperature increase of 30°C will increase in length 0.89mm. Conversely, materials will contract and shrink with a decrease in temperature, and because thermal movement is a reversible phenomenon (Hinks and Cook 1995:105), the material will return to its original dimensions.

The implications of material expansion or contraction to a building can range from insignificant to disastrous. An overall increase in length of 2 mm over the span of 30m, for example, would be relatively inconsequential to the building as a whole. However, if that same material was adjacent to one or more other materials, all with different expansion coefficients, then the original 2 mm could contribute exponentially to a significant shift in size. For example, cracking (figure 3.18), buckling and detachment are all symptoms of thermal movement in materials. While the problems are unsightly, they can lead to significant problems in the building envelope, resulting in water infiltration, air leakage, or building deterioration.

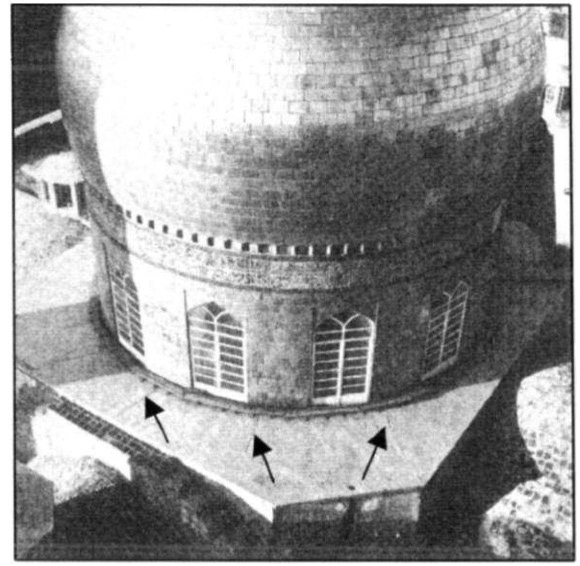


Fig 3.18 This Holy Shrine in Iraq shows evidence of thermal cracking due to large daily changes in temperature.

The moisture content in materials will also affect how it responds to temperature change. Unlike many materials that will contract when cooled, water will expand 9% of its volume when it freezes and changes from a liquid to a solid. If a material contains any water or moisture when it is subjected to subzero conditions, then the water will expand while the material itself will contract. The result is a force so strong that it will crack the component or even result in spalling on the surface of the material (figure 3.19).

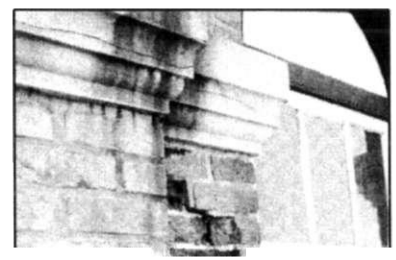


Fig 3.19 Migrating moisture through bricks could freeze and cause spalling on the surface of the material

3.3.10. THE WEAKEST COMPONENT WILL FAIL FIRST

A chain is only as strong as its weakest link. This saying is used in many contexts to describe a myriad of situations. In this discussion, it is particularly relevant, as a building is only as strong as its weakest component. Because buildings are comprised of systems and components, the durability of the building as a whole is contingent upon the durability of its constituent parts. As with the weak link in a chain, the weakest of a building's components will naturally fail first, jeopardizing the rest of the system, regardless of the durability of other components.

3.3.11. NO MATERIAL IS INFINITELY STRONG

Modern technology strives to invent and produce materials "better" than the previous generation. For example, the "New Steel" is marketed as a product that is stronger, lighter and more versatile than its predecessors Similarly, manufactured lumber companies are constantly attempting to make bigger and better products and designers are pushing the limits of these technologies (figure 3.20). Technology may succeed in manufacturing materials that are immediately "better" and can be used in more innovative and unique situations, but no material is infinitely strong; there is a point of fatigue or failure for *every* material. Therefore, for every design situation, there is an optimal limit for the materials used. No material is infinitely strong, and there are limits to how they can perform.

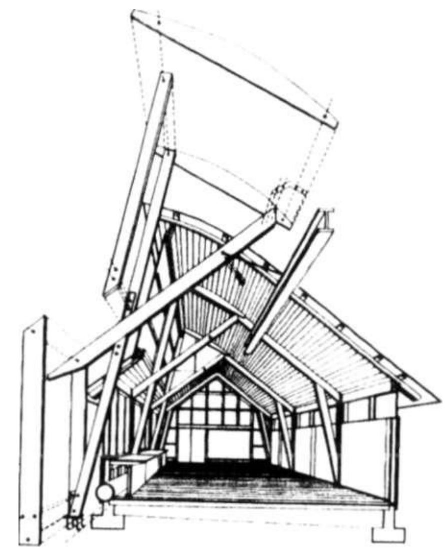


Fig 3.20 New products are constantly developed that profess to be bigger, better and stronger. This design uses new lumber technology in an innovative way

3.4 FUNCTIONAL REQUIREMENTS

To many people, buildings are simply designed, built and used as part of everyday life. Embodied in this service is the presumption that the building will function as it was originally intended. In fact buildings themselves have requirements that must be outlined and met in order for it to perform successfully as a building.

3.4.1 STABILITY

Buildings are constructed from disparate materials and erected into a whole. At a basic level, occupants rely upon the structure that has been built to provide protection. The built structure therefore must be stable so as to remain in the "built position." Stability of the structure is also essential to the well-being of the occupants. While resisting the force of various loads (wind or snow loading), the structure must also remain stable so as to not collapse on the occupants (figure 3.21), as "the exterior wall itself must not be a hazard to life or property" (Hutcheon 1963:1). Therefore it is essential that the building have stability to remain in its intended form and to protect itself, the property and the occupants within.

Fig 3.21 Stability is a functional requirement of all buildings. The building should be built to withstand loads and protect occupants

3.4.2 DURABILITY

We build buildings to last. This is often a general assumption in modern construction, as there is such an enormous resource investment in the construction of any building; we expect it to "last." But for how long? The amount of time that a building is meant to function or "last" will depend upon its durability. Durability is defined as "the ability of a building ... to perform its required function over time in spite of degrading forces that act upon it" (Kent Donis 1997:135). Degrading forces act upon a building from both within and without and include general wear-and-tear of use, wind, rain, snow, hail, sleet, sunlight, fire and structural movement. Therefore design and material choices are made in an attempt to ensure that the rate of deterioration will not impair the functional requirements of the building during its intended life span. For example, if a roof system begins to deteriorate and leak water into a building, then this deterioration is interfering with the functioning of the building. It could be said therefore that this building is not durable. If however, a superior roof system was originally installed on the building, it is likely that the building would have continued to perform its required function despite degrading forces, and would have been a more durable building.

Central to the concept of durability is the intended life span of the building. Initially we would deem a building that collapsed after ten days to be a poorly designed building, with shoddy materials and inferior workmanship; in short, we would assess that it was not a durable building (figure 3.22). However, if you were told that the intended life span of the building was five days, then would it not be assessed, based on the criteria established above, that this building was a durable building? It was built with the intention of lasting for five days, and it lasted ten days! Is this not 100% longer than originally intended? This example illustrates that it is imperative to understand the intended life span of the building before assessing its durability.

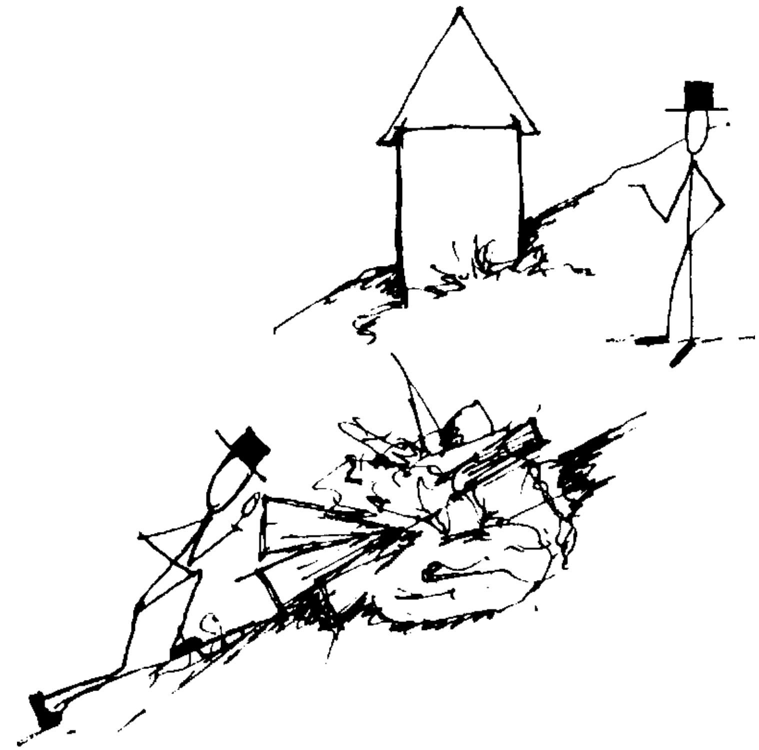


Fig 3.22 Just because a standing structure falls down doesn't mean that it isn't durable.

3.4.3 EMBODIED COMMODITY

There is an investment in every building. As the construction of any building requires both resources and labour, the investment is embodied in the very existence of the structure itself. In a modern context investment will immediately connote a capital expenditure, and any commodity input to the construction of a building is manifest in the "bottom line", the cost in a dollar amount. Therefore, every aspect of construction, including labour and materials is converted to a value in dollars. If a building cost one million dollars to build, then that is one million dollars worth of materials and labour, and is the embodied commodity of the building. Implicit in this cost are any design decisions, such as quality of materials (which naturally affects durability).

However, in a situation where dollar amounts are not considered (an impossibility to many modern thinkers) investment value still exists. If we define commodity as any investment embodied in the design and manufacture of a structure, then every building will have embodied commodity, as both labour and materials are needed to construct any building. If you are constructing a shed in your back yard, you are likely to consider only the materials you purchased at the hardware store when assessing the final cost of the structure. What price would you put on your own hours of labour to construct the building? Cultures of the past similarly would have made decisions that affected the embodied commodity of their buildings. If a temporary shelter was needed for hunting, it is likely that the most prized construction materials would not have been used, and it is likely that a limited number of labour hours would have been expended in building the shelter. Alternatively, many cultures through time have launched massive expenditures for religious and culturally significant buildings. The pyramids of Egypt, the great cathedrals of Europe, and the temples of India all embody a massive commodity input (figure 3.23). Every

Fig 3.23 The great buildings of the world embody a huge commodity in materials, labour and resources

building must have materials to be constructed of, and must have labour to construct it. Therefore, every building embodies the commodity input to its construction.

3.5 BUILDING SCIENCE AND THE INTERRELATED SYSTEM OF BUILDING

The essence of building science lies in understanding the interrelationship of the three areas that compose the discipline: the physical elements, the principles and the functional requirements. While each of the three areas are often analysed individually, it is the idea that each is part of the greater whole that builds the holistic perspective of building science (figure 3.24). In understanding that a building, and therefore the analysis of the building, is many faceted and extends beyond a usual material analysis, will lead any investigation to understanding a building in a similarly holistic way.

Fig 3.24 The essence of building science is understanding the interrelationship of the three areas within the discipline

Furthermore, the rational for the previous discussion, which centered upon exploring the base elements of the discipline facilitated a view that all buildings can be analyzed by this discipline. Thus other disciplines that might investigate buildings can utilise building science to illuminate their own understanding of the building. The interdisciplinary nature of this new paradigm will allow building science to provide intimate knowledge of any given building and will contribute to the research of many disciplines, rendering building science an influential and powerful interdisciplinary tool for architectural analysis.

3.6 SPHERES OF INFLUENCE

The preceding discussion of building science focussed on investigating the foundation of the discipline, and in so doing, looked at the very essence of what comprises a building, and by extension, what comprises *every* building. Although there certainly are (and were) buildings that can be described within such restricted parameters (a rudimentary shelter for example), most buildings, from the past and the present, are more complex. This raises the following questions: how is the base building different from most other buildings? And what is it that makes buildings so different from one another (figure 3.25)?

Fig 3.25 The Acropolis and the Empire State Building are obviously very different from one another. But why?

The primary function of every building is to protect the occupants. *How* the building protects is the quality that makes each building distinct. While every building is the same at a basic level of protection, there are layers of difference that make buildings distinct. These can be categorized into two areas: geographic location and cultural influences. These are the factors that influence the design of a building, the factors that influence how and why a building is built.

3.6.1 Geographical Location

The geographic location of a building will naturally influence to a certain extent how and why it is designed and built. Factors such as climate, localized geography and available resources will all influence a building's construction. For instance, it is unlikely that a grass or reed shelter would be constructed in a cold climate. Likewise, bulky thermally insulated walls are not likely needed in a warm climate. Therefore, the geographic location of a building will often influence the design of a building.

3.6.2 Cultural Influences

Cultural influences are culturally related spheres that will effect how a building is designed, built, used and the nature of the protection that it provides for the occupants. Cultural influences can include technology, politics, religion, history, economy, ethics, sex, health and education (see Appendix A for formal definitions of these terms). For example, the technology available may determine how a building is built, the materials used, and the durability of that building. Similarly, religion could also dictate how a building is designed and built; the shape, the materials, the durability. In fact, a scenario could exist where the technology to achieve a complex design is available, but the religious beliefs and traditions of the culture will dictate a different but more simple building. The extent to which each cultural factor will influence the design and construction of a building will vary significantly for every culture and every building,

> Each culture has different expectations of its [buildings], and makes demands on them which are related to its social structure and to the ways in which its members organize their daily lives
> (Oliver 1987:128).

Therefore, it is imperative to acknowledge cultural differences when investigating, analyzing and appreciating any building. A 'simple' building is not necessarily indicative of a 'simple' culture.

By adopting this approach to buildings and their inception, we begin to realize that a "building reflects contemporary attitudes towards environmental control, structural concepts and aesthetic excellence" (Osborn 1985:2). A building that is several thousand years old will reflect attitudes prevalent several thousand years ago, even though they may contradict attitudes of today. The impression that cultural influences will have on the design and construction of a building is significant. Combined with the influence of geographic location, these spheres of influence are the impetus behind the individuality of each building.

3.7 SUMMARY

Building science is a discipline that can be used to analyze any building, from any time period and any geographical location. The component parts of the discipline comprise the essence of building science, and provide a forum for a holistic view and analysis of any building. The physical elements, the principles and functional requirements of a building combine to create a versatile interrelationship that mirrors that found in actual buildings: an interrelationship of components parts that form the whole. Very few buildings however, can be described within such simple parameters. The spheres of influence are those factors that render buildings different from one another, distinct reflections of the societies and cultures that designed, built and used them. Buildings are a complex cultural phenomena that are part of our everyday lives. Building science can help us to attain a greater understanding of them, the cultures that produced them and the people that used them.

CHAPTER. 4: METHODOLOGY

METHOD FOR. ANALYSIS

The objective of this thesis is to illustrate how building science can be used as an integral component to interdisciplinary examinations of buildings before they are built, while they are standing, and after they have fallen down. The analysis must therefore strive to emphasize the analytical ability of building science to investigate buildings through time.

To formulate a methodology for analysis, it is imperative to look back at the framework established to describe building science. There are three areas that comprise the discipline:

1. the **physical elements** of the building
2. the **principles** of materials and components
3. the **functional requirements** of every building

In order for this study to investigate a building in a holistic way, the following analysis will occur:

> the physical elements of a building will be assessed based on the guidelines of each principle, and the results will be evaluated against each of the three functional requirements (see figure 4.1 on page 65).

This methodology will ensure that a thorough and holistic analysis of each case study will ensue. The following questions will be posited for each of the case study buildings:

	PRINCIPLES	QULS1 ION TO I.VALUA 11 Ill1 FUNGI IONAI. Rt.QUIIUM N IS
1	FORCES EXIST TO ACHIEVE A BALANCE	W/h?)t arf* thp tnrrp^ at work in or o nthp hnilHino^ How no thpv fittPiYint to achieve a balance? Will achieving this balance affect the stability, durability or commodity of the building?
2	THERE IS ALWAYS A POINT OF DIMINISHING RETURN	With most design decisions, there is a point of diminishing return. Have the design decisions that have been made maximized the potential of the materials, components and systems? How do these decisions affect the stability, durability and commodity of the building?
3	HEAT TRAVELS FROM THE HOT TO THE COLD	Does the heat travel from the inside to the outside of the building, or vice versa? How will this heat flow affect the stability, durability, and commodity of the building?
4	THE GREATER THE DIFFERENCE IN TEMPERATURE THE GREATER THE HEAT TRANSFER	Will increased heat transfer through the building envelope affect the stability, durability, and commodity of the building?

5	HEAT CONDUCTION WILL ALWAYS OCCUR	What efforts have been made to slow the conduction of heat through the building envelope? How do these efforts affect the stability, durability, and commodity of the building?
6	MATERIALS WILL NOT DETERIORATE IF ONE OF THE CONDITIONS FOR DETERIORATION IS ABSENT	What are the conditions for deterioration of the materials in the building? Which of these conditions are present? How will these conditions affect the stability, durability and commodity of the building?
7	MATERIALS MUST HAVE SUFFICIENT TIME TO CURE UNDER OPTIMAL CONDITIONS	What are the main materials in the building what are the optimal curing conditions that would be would be required? If they were not cured properly, would this affect the stability, durability and commodity of the building?
8	MOISTURE CAN CHANGE THE PROPERTIES OF MATERIALS	How will moisture affect each building material? How will these properties affect the stability, durability and commodity of the building?
9	MATERIALS CHANGE DIMENSION WITH TEMPERATURE CHANGE	How do the materials react to changes in temperature? How will this affect the stability, durability and commodity of the building?
10	THE WEAKEST MATERIAL WILL FAIL FIRST	What is the strongest material in the building? What is the weakest material? If the weakest material were to fail, how would this affect the stability, durability and commodity of the building?
11	NO MATERIAL IS INFINITELY STRONG	What will affect the strength of the building materials? Will this affect the stability, durability and commodity of the building?

Three buildings will be evaluated as part of the analysis. A full description and discussion of each building is presented in Chapter 5.

In order to simplify the analysis, the three buildings are all located in the same climate within the same geographic location, the Canadian High Arctic. The following chapter 5 will present a brief background to the Arctic climate and each case study building, and the analysis will ensue in chapter 6.

PHYSICAL ELEMENTS
OF THE BUILDING

The physical elements of a building will be assessed based upon the guidelines of each principle, and the results will be evaluated against each of the three functional requirements

PRINCIPLES OF MATERIALS
AND COMPONENTS

FUNCTIONAL REQUIREMENTS
OF EVERY BUILDING

Durability
Stability
Commodity

Forces exist to achieve a balance

There is always a point of diminishing return

Heat travels to the colder side — Durability, Stability, Commodity

The greater the difference in temperature, the greater the heat transfer — Durability, Stability, Commodity

Heat transfer by conduction will always occur — Durability, Stability, Commodity

Materials will not deteriorate if one of the conditions for deterioration is absent — Durability, Stability, Commodity

Materials must have sufficient time to cure under optimal conditions — Durability, Stability, Commodity

Moisture can change the properties of materials — Durability, Stability, Commodity

Materials change dimension with temperature change — Durability, Stability, Commodity

The weakest material will fail first — Durability, Stability, Commodity

No material is infinitely strong — Durability, Stability, Commodity

Fig 4.1 Schematic for a Building Science Analysis

CHAPTER 5: CASE STUDIES

BACKGROUND

Initial nineteenth and twentieth century impressions of the Inuit have become icons of popular culture (figure 5.1). Images of dogsleds and igloos, whale blubber and parkas are well recognized symbols of the Canadian north. These simple impressions, however, belie a much more complex culture adapted to an equally complex and harsh climate. As the arctic is characterized by extremes not only in temperature, but also wind, sunlight and precipitation, the Inuit culture has over time had to adapt to live in these extraordinary conditions. Survival strategies are not only unique but also essential. Inuit versatility and adaptability is typified by the production of shelter to protect them from the environment and local predators.

This chapter provides a brief summary of the arctic climate, followed by a short description of the Central Arctic, the specific climatic zone in which the case study buildings are situated. An outline of Inuit culture history follows, which traces the Inuit through several hundred years into a modern context. The

Fig 5.1 The mystique of the Arctic has been a popular movie theme for decades

intention of these two sections is to familiarize the reader with both the natural and cultural factors that influence the design of any shelter in the Canadian Arctic.

5.1 CLIMATE AND GEOGRAPHY OF THE CANADIAN ARCTIC

Did you know that

In some areas of the Arctic the sun sets on October 22 and does not rise again until March 1 of the next year (Bruemmer 1971:18)

Half of Canada's landmass is permafrost? (Strub 1996:26)

The Northwest Territories has a density of approximately one person per 52 square kilometers of land (Strub 1996:7)

These are some of the unique characteristics of the Canadian Arctic. This area is generally identified as the land north of the tree line, which is the northern limit of the extensive boreal forest (Stager & McSkimmings 1984:27). Although "the Arctic" extends from Alaska to Greenland, this discussion will focus on the Canadian Arctic, or that part of the Arctic within the legal borders of Canada (figure 5.2).

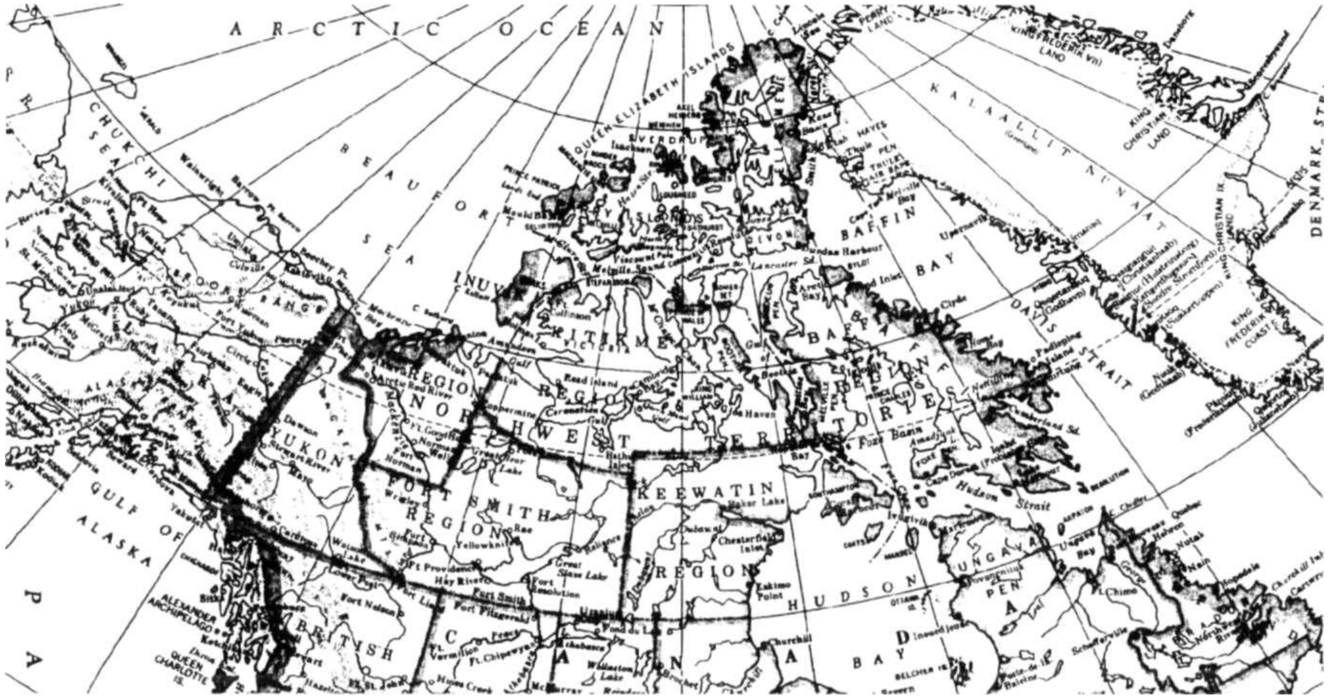


Fig 5.2 Map of the Canadian Arctic

5.1.1 CLIMATE

As discussed in chapter 2, climate plays a central role in the development and construction of shelter forms. Particularly in the harsh climate of the north, there are several aspects of the Arctic climate that significantly influence both the design and construction of shelter: sunlight, air temperature, precipitation and wind.

5.1.1.1 Sunlight

The climate of the Arctic is strongly affected by the amount of sunlight that it receives. Because of the rotation and tilt of the earth, the polar regions of the earth obtain very weak and seasonal sunlight. Although the actual total number of hours of sunlight received by the Arctic in one year does not greatly differ from other lower latitude areas, the *distribution* of that sunlight does differ widely according to latitude. Figure 5.3 illustrates that as the latitude increases, so does daylight become a seasonal phenomenon. The Arctic Circle (66°32') marks the northern limit of the year-round occurrence of daily alternating daylight and darkness. Above this latitude, at 90°N for example, there are times of the year when the sun does not set. Alternatively, at the same location, the sun does not rise from November to January, and the people of this high latitude live in 24-hour darkness.

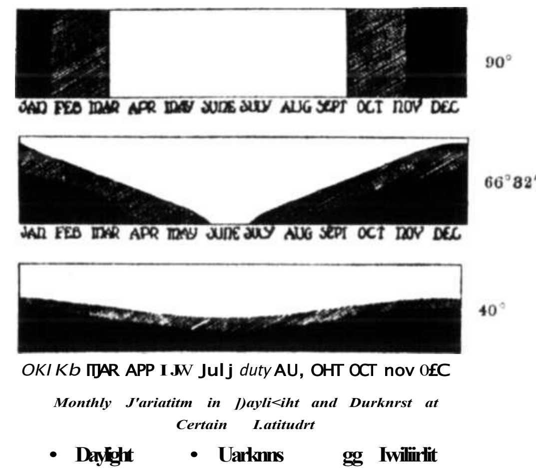


Fig 5.3 Monthly variation in daylight and darkness at three different latitudes.

The quantity and strength of sunlight also determines the temperature of the air and earth in the region. "The height of the sun above the horizon influences the amount of its heat received at any point on the earth" (Weyer 1962:18). Because the sun is low on the horizon, the arctic regions receive very little heat from the sun's rays (figure 5.4). This will directly affect the air and landmass temperatures (see also the section on permafrost below). As a result, heat from the sun is nominal, and Harold Strub comments that the fluctuation in the sun's heat also signals the changing seasons: "one day the sun has a warming effect on the skin;

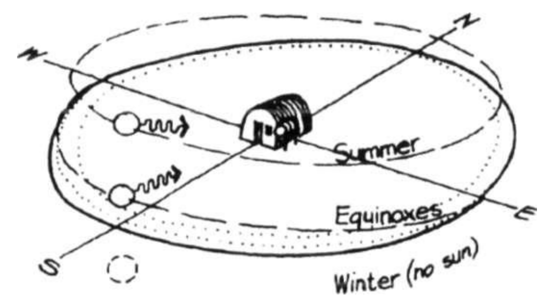


Fig 5.4 Because the sun is low on the horizon, the polar regions receive very little heat from the sun's rays

the next, nothing" (Strub 1998:41). Shifts are so abrupt that inhabitants of the Arctic can *feel* a seasonal change.

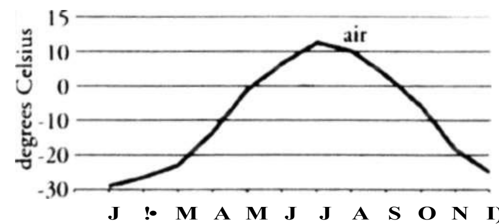


Fig 5.5 Mean daily temperature averaged for eight northern communities in Canada

5.1.1.2 Air Temperature

The Arctic is perhaps best known for its cold temperatures, which are detailed in figure 5.5. The average temperature for the winter months ranges from -20°C to -30°C, and in only four months of the year does the average air temperature ever rise above the freezing point. Although there are marked regional differences in the air temperature, summers are generally short and winters long.

5.1.1.3 Precipitation

Visions of the Arctic as a snow-covered landscape are common. Factors such as cold air (with a low vapour carrying capacity) and high winds, however, result in low annual snow-fall and low precipitation in most areas. This has lead many to refer to the arctic as a "polar desert" (Strub 1998:50). Figure 5.6 shows that although most precipitation occurs in the summer and most snow falls in the late fall, in any given year it is common to have annual precipitation totals to be less than 250 mm (Calgary, on average, will have 400 mm per year).

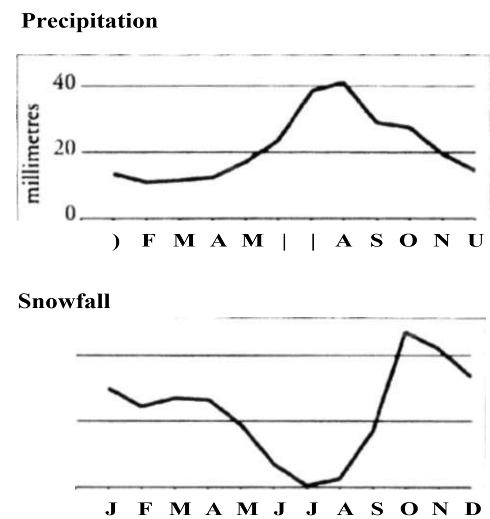
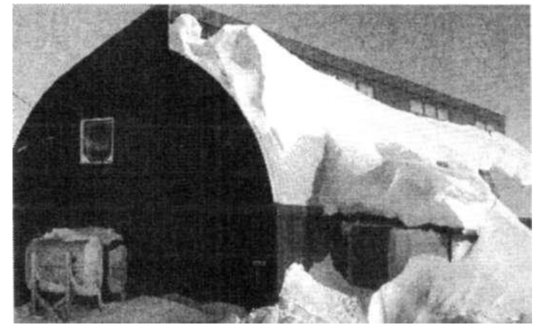


Fig 5.6 Total precipitation and snowfall (in millimetres) averaged for eight northern communities in Canada

5.1.1.4 Wind

Wind is ever-present in the arctic. Harold Strub professes that "wind persists almost as much as the force of gravity" (Strub 1998:48). The result is a force that effects every aspect of the natural and man-made environment. Wind can move snow (figure 5.7), sand and grasses. It steals heat, evaporates moisture and destroys habitats. It can move sea ice and change the landscape. The omnipresent character of wind is one of the considerations in understanding Arctic life and subsistence.



^7J*f, •

Fig 5.7 Lee side snow drift. The arctic wind can deposit incredible amounts of snow.

5.1.2 GEOGRAPHY

Consideration of the geography of the Arctic is paramount in the design and construction of shelter. Both unique landforms and permanently frozen ground (permafrost) will not only guide design, but will serve to restrict it also.

5.1.2.1 Landforms

The most notable characteristic of the Canadian Arctic is its lack of trees (although some areas of the western Arctic have this resource in abundance). This presents a barren landscape without any vertical reference, which presents difficulties in distinguishing distances. The Arctic geography can also be diverse with large coastal expanses commingled with tundra and mountain ranges.

5.1.2.2 Permafrost

The air temperature directly affects the ground temperature. In areas where the mean annual air temperature is consistently below freezing, the ground is permanently frozen. This type of ground is known as permafrost. During the summer months where air temperatures rise above 0°C, the surface of the ground will begin to melt. Only one or two feet of the surface soil is never truly free of ice (Weyer 1962:28). Below this zone, the ground remains frozen. As temperatures fall during the winter months, the melted soil quickly freezes rendering the ground impenetrable.

5.1.3 THE CENTRAL ARCTIC

The Central Canadian Arctic[1] has been described as "the area lying between the northern limit of timber and the Arctic coast has frequently been referred to as the "barren lands'" (Weyer 1962:12). Although this area has generally the same characteristics as the rest of the Arctic, there are several noteworthy facts that make the Central Arctic distinct from the other Arctic areas. For instance, the Central Arctic is covered in grasses and heather and is mostly devoid of trees

For purposes of this paper, the Central Arctic will include the areas of the High Arctic and the Keewatin District.

(figure 5.8). It is also noted for the incessant wind that strips the land of moisture and snow cover. As a result, this particular area of the Arctic provides very little for both subsistence and shelter construction.

Fig 5.8 Much of the Central Arctic is void of tress and barren of large mammals

5.2 CULTURE HISTORY OF THE INUIT

5.2.1 INUIT PREHISTORY

The Thule culture are said to be the ancestors of the modern Inuit and originated in Alaska, where they developed advanced strategies for living and surviving a coastal lifestyle. Approximately AD 1000, this population began to migrate[2] eastward into all parts of the area now known as the Canadian Arctic (McGhee 1983-84). The Thule people specialized in open water hunting of sea mammals, such as the Balean whale (Collins 1984:15), and made use of the whale skeleton as structural elements in their permanent semi-subtenanean houses (figure 5.9).

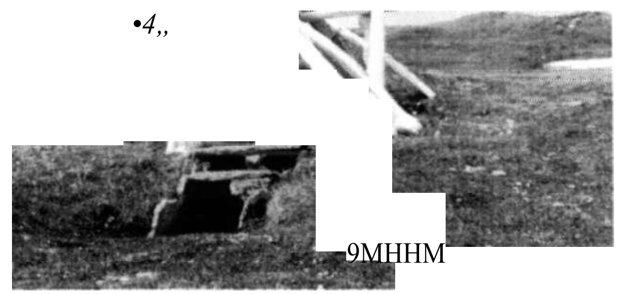


Fig 5.9 A reconstruction of a Thule Whalebone House in Resolute Bay, NWT.

The origin and migration of this group of prehistoric inhabitants of the Arctic is a point of intense archaeological debate. For the purposes of this discussion, the most common explanation in modern archaeology has been employed.

At approximately AD 1200, deteriorating climatic conditions resulted in a marked decrease, and eventual cessation, of whaling activities by the Thule, who had to move south following migrating herds of land animals.

5.2.2 EUROPEAN CONTACT

Although the first European contact with Inuit people likely occurred in 1000 AD when Norsemen arrived to the North American continent, it was about 500 years later that the first European explorers penetrated the Arctic. In 1576, Martin Frobisher charted a path into the Arctic in search of a passage to China. He was the first in a long line of explorers that continued well into the 1850's (including Sir John Franklin of the ill-fated Franklin Expedition). Generally, early European contact in the Arctic was peaceful in nature, which is in sharp contrast to other European landings in the Americas. This was due to several factors: a small native population that was not a threat to the explorers, unproductive soil, and a lack of precious metals. The result was several hundred years of coexistence between European explorers and Inuit people (Neatby 1984).

By the 18th century, fur trade posts were established, and the Inuit were trading pelts for glass beads, metal, tea, sugar, tobacco and guns. More time was spent hunting for trade items, and less time hunting for food, which resulted in the development of seasonal shanty-towns around the trading posts.

5.2.3 POST WWII

Until the late 1940's the Canadian government remained detached from activities in the Canadian North. After WWII however, with reports of disease and destitution among the northern Inuit populations, "the Canadian government mobilized itself...to bring support services to remote settlements" (Strub 1996:63). The result was the development of the Inuit Rental Housing Program, directed by the Department of Indian and Northern Affairs. This program aimed to house the Inuit in "respectable" affordable housing and to educate them on how to correctly live in these houses. Figures 5.10 shows one of the booklets used in the education programs, and included such topics as teaching Inuit women how to be good homemakers and Inuit men how to be good providers and breadwinners. Climatic constraints and construction costs dictated prefabricated house design, with little or no attention to the cultural and individual needs.

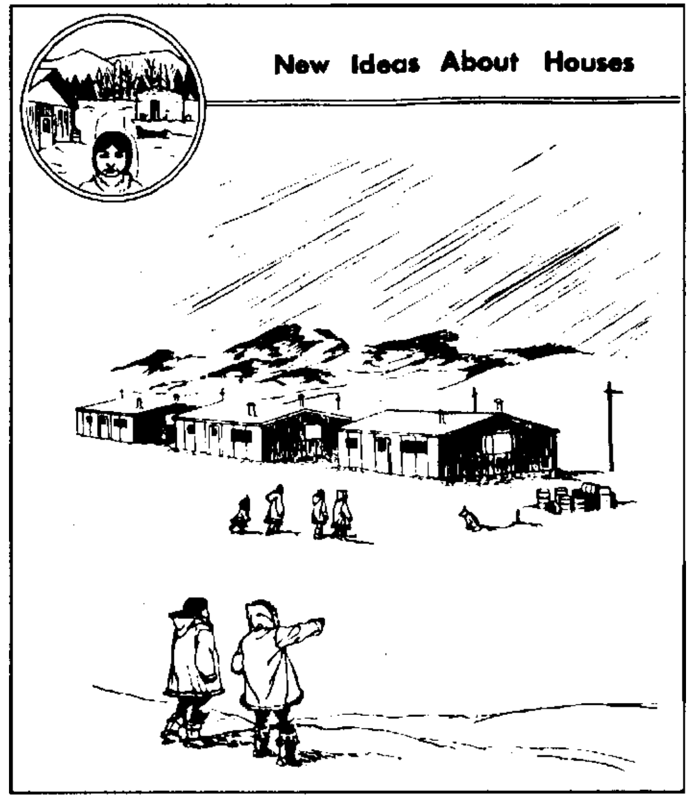


Fig 5.10 Front cover from an Inuit Rental Housing Program booklet

5.3 THREE EXAMPLES OF ARCTIC CONSTRUCTION

There are three buildings that will be considered as part of a discussion on arctic construction:

- Whalebone house, circa 1500AD
- Snowhouse, circa 1900AD
- Coldstream house, circa 1980AD

Each building is located in the Central Canadian High Arctic, and each was constructed and used during a distinctly different time period. This section will provide a brief background to each building and a comprehensive description of the materials and construction techniques that were employed. The information for each building is presented in two areas: a written description below and an attached layout sheet that visually represents the materials and construction of each building. These two presentation media are meant to used together, and present a complete understanding of each building.

5.3.1 "WHALEBONE HOUSE, CIRCA 1500AD

Whalebone houses (figure 5.11) are a unique and specialized form of construction used by the Thule Inuit culture for approximately 250 years

Fig **5 11** A reconstruction of the structure of a whalebone house, Resolute Bay, N.W.T.

in the Canadian High Arctic. The buildings represent a cultural adaptation to a harsh climate that reflected their specialization in marine mammal hunting. The Inuit used the bones of the Baleen Whale skeleton and sinew to construct the supporting structure of the whalebone house (figure 5.12 & 5.13). Over this structure a hide was stretched, which was then covered in peat and then packed with snow. Although the hide served as a surface on which to construct the outer wall, it also served to give the house added stability and structure. The base of the building was excavated approximately three feet into the ground, creating a semi-subterranean dwelling. The entrance and floor of the house were lined with flat stones, most often slate. These permanent winter houses were relatively uniform in size, and were used by a family or community for the duration of one winter. The hide and bone structure, however were valuable resources and were kept for use in the following winter seasons. It is important to note that the exact construction of the Whalebone house is still a topic of discussion among archaeologists. This is because the outer materials of the house are perishable and leave no tangible evidence in the archaeological record. Therefore, future research may reveal new information leading to a more complete understanding of the materials and method of construction.

Construction of the houses began in late summer or early fall, while the ground could still be excavated Typically, one large house would use approximately 30 mandible support beams, representing at least 15

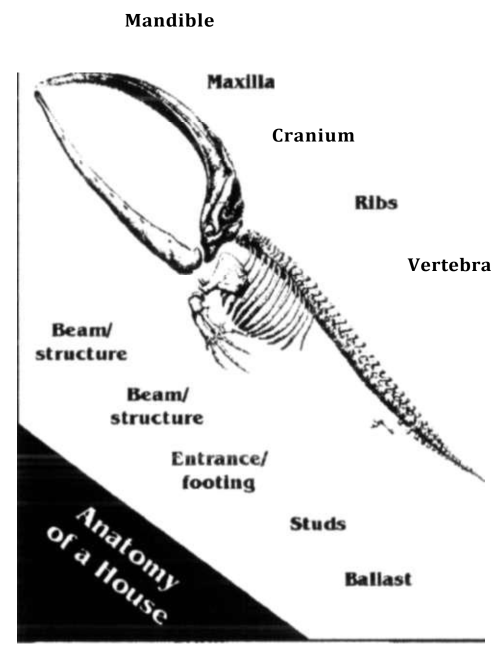


Fig 5.12 The skeleton of a Balean Whale was used to construct the structure of a whalebone house

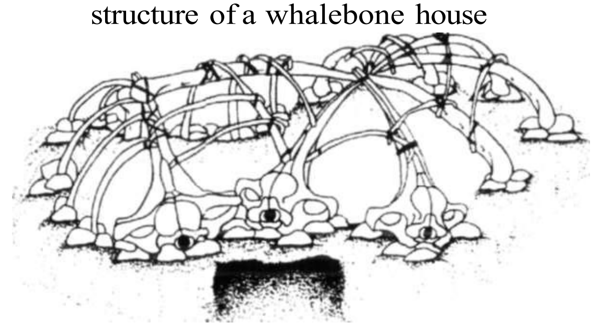


Fig 5.13 The structure of a whalebone house is constructed using the skeleton of a Balean Whale

individual whales. As a community would only hunt one or two whales in one season (in addition to any beached carcasses), the seemingly extravagant use of materials was necessary for constructing the building and represents a large investment of human and material resources.

Fig 5.14 The abandoned remains of a whalebone house

The remains of the whalebone houses can be found in the barren landscape, sitting abandoned. It is very common however, to find that the bones have been scavenged for other purposes, such as carving or construction of new residences. Following the decline of the whaling way of life, these buildings became obsolete. Their remains can still be seen on the Arctic landscape (figure 5.14).

5.3.2 SNOWHOUSE, CIRCA 1900AD

The traditional Inuit snowhouse, also known as the igloo, has become a symbol of northern culture and an archetype of climatic adaptation. While the stereotypical igloo (figure 5.15) connotes images of living in isolation, in extreme conditions with limited resources, the building itself is actually a remarkable example of ingenuity and resourcefulness in a banen landscape.

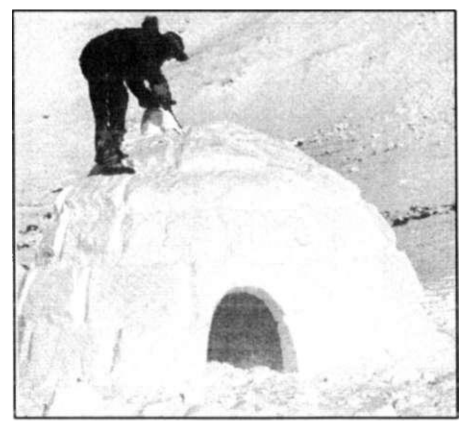


Fig 5.15 A complete snowhouse

A snowhouse is built out of a snowdrift. The location of the building is determined completely by the location of a snowdrift that contains snow of the quality and consistency necessary to build the snowhouse. Namely, the snowdrift must have compact snow that has all been laid down during one snowstorm. Snow from various storms will have stratified layers that are not stable. A su lung' or bone knife, is used to cut blocks of snow out of the snowdrift, which are then built up in a circular pattern to form the igloo (figure 5.16). The structure of the building is achieved by the blocks, which are shimmed to fit snuggly and lean on the adjacent block. The depression where the snow has been taken from in the drift forms the entrance tunnel floor of the snowhouse and the surface of the snowdrift forms the sleeping platforms. Every attempt is made to build the snowhouse in the lee of the drift or any other prominent feature, with the opening away from the wind.

T-

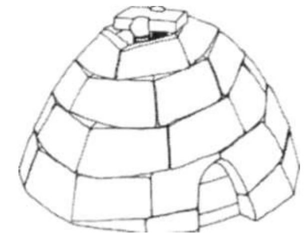


Fig 5.16 A snowhouse is built up in a circular pattern

pjg 5 1 7 Some large snowhouses can accommodate many people

Snowhouses are built and used during the winter months from October to May and can vary significantly in size. A temporary "journey" snowhouse, that is approximately 5ft high and 7ft in diameter will take two skilled men 1-2 hours to build and be used for approximately 2-3 days. A more permanent home however, with a dome height of 10-12 ft high and the interior space 15 ft in diameter would take a few more people less than a day to construct (figure 5.17).

There are reports of buildings such as these being occupied for several weeks and even up to several months. The interior of the snowhouse remains warm from the heat emitted by occupants and from the heat generated from the *k$_u$Uq,* a stone lamp that burns seal fat.

Fig 5.18 "A Tribute to Vinyl Siding"

The snowhouse is a building that utilizes materials where they are quarried, eliminating expenditure for transport and extensive handling. The only tools needed in construction are a $_{su}l_{un}g$, or stone knife. This vernacular style has in fact become respected as the epitome of a functional dwelling. Many modem designs have attempted to emulate the form and combine it with modem innovations in materials and technology (figure 5.18). For example, attempts to replicate the design in a modem context have been executed in rigid foam, wood and papier mache. The building has also been replicated on a grand scale (figure 5.19) such as with this example of a hotel in the Alaska.

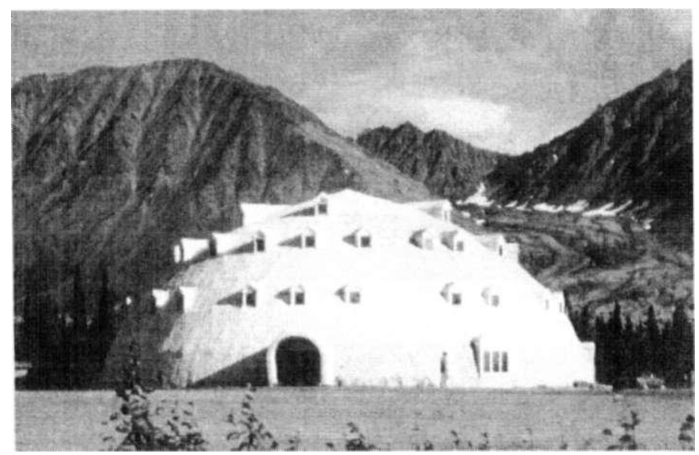


Fig 5.19 Attempts have been made to use snowhouse technology on a large scale, such as this hotel in Alaska

Although the snowhouse is still in use today as a temporary shelter while hunting, they were essential to survival during the 18th and 19th centuries. Snowhouses are virtually impossible to locate archaeologically, as the material used to construct the shelter melts and disappears in the spring. Furthermore, the dwellings were often built on the ice pack, which itself would melt and leave no evidence of a footprint. On the rare occasion when a snowhouse had been built on land, rock formations or debris sometimes reveal their presence. Generally however, the presence of the snow knife is the only evidence of their existence during this time. As a result, traditional knowledge handed down by the Inuit themselves has helped modern studies to analyze the snowhouse, and wonder at the ingenuity of the Inuit of 200 years ago.

5.3.3 Prefabricated "Coldstream" House, circa 1980AD

When the Canadian Government began to take an interest in the welfare of the people of the Canadian North, their immediate mandate was to provide suitable housing. This generated a sector of the construction and research industries that focused solely on the design and construction of affordable housing for the Inuit. Issues of prefabrication quickly came to the fore as raw materials were non-existent in the north and costs for shipping and construction in isolation were astronomical.

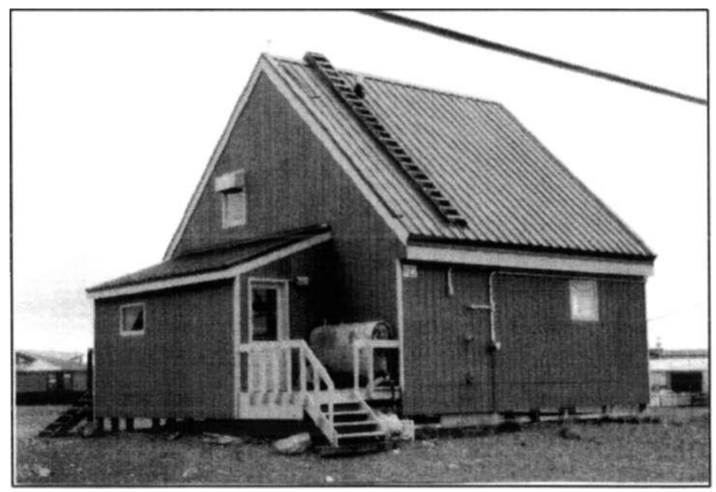
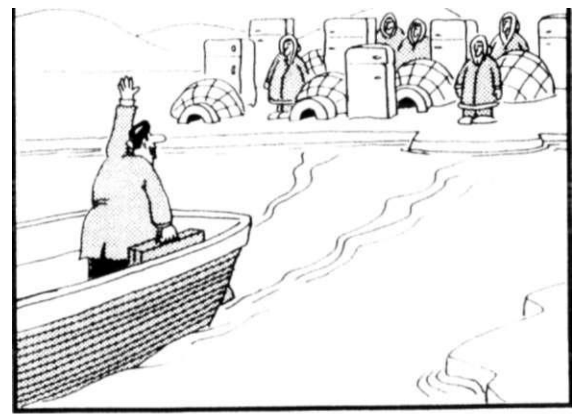


Fig 5.20 An example of a Coldstream house in Arviat, Nunavut

The Coldstream House was designed in the early 1980's by a Winnipeg design firm, *#10 Architectural Group,* in conjunction with Canada Mortgage and Housing Corporation (CMHC) and the Department of Indian and Northern Affairs (figure 5.20). The primary design directive was to maximize the interior area of the house while minimizing the exterior surface area. The technology was a prefabricated panel system that could be easily and quickly assembled on site, required little expertise in construction and needed little or no finishing (ie. exterior siding or interior finish). In this way, the building could be erected quickly and inexpensively in remote locations. The prefabricated panels were comprised of expanded polystyrene clad with metal. The panels used for the walls were 5" thick and the roof panels were 7" thick, and were attached on the outside of a traditional wood frame. This design, borrowed from current refrigeration technology, is reminiscent of the popular saying "Its like selling refrigerators to the Eskimos" (figure 5.21). The lightweight, thermally efficient panels could easily be shipped to the North and assembled on site using 'unskilled labour.' The result was a building system that could be manufactured in the south, and shipped to any remote location for assembly, thereby ensuring a 'proper' standard of living for the communities of the north. Although the designers, manufacturers and government officials had high hopes for this house type, only 24 were manufactured and assembled. Once in use, occupants noted the delamination of the metal cladding from the interior insulation. It was deemed to be uneconomical to continue development.

THE FAR SIDE By GARY LARSON



Ralph Harrison, king of salespersons.

Fig **5.21** Prefabricated housing based upon refrigeration technology spawned the saying "its like selling refrigerators to Eskimos"

5.4 PREVIEW TO THE ANALYSIS

The climate and geography of the Canadian High Arctic are harsh and extreme. The Inuit however, have for hundreds of years adapted to this environment and successfully survived in the face of adversity. The survey of construction types has discussed the range of buildings through time that have been built to survive this harsh climate. Chapter 6 will investigate the buildings from a different perspective, through the lens of building science.

SNOWHOUSE

SPECIFICATIONS

Date of Construction:
circa 1900 AD

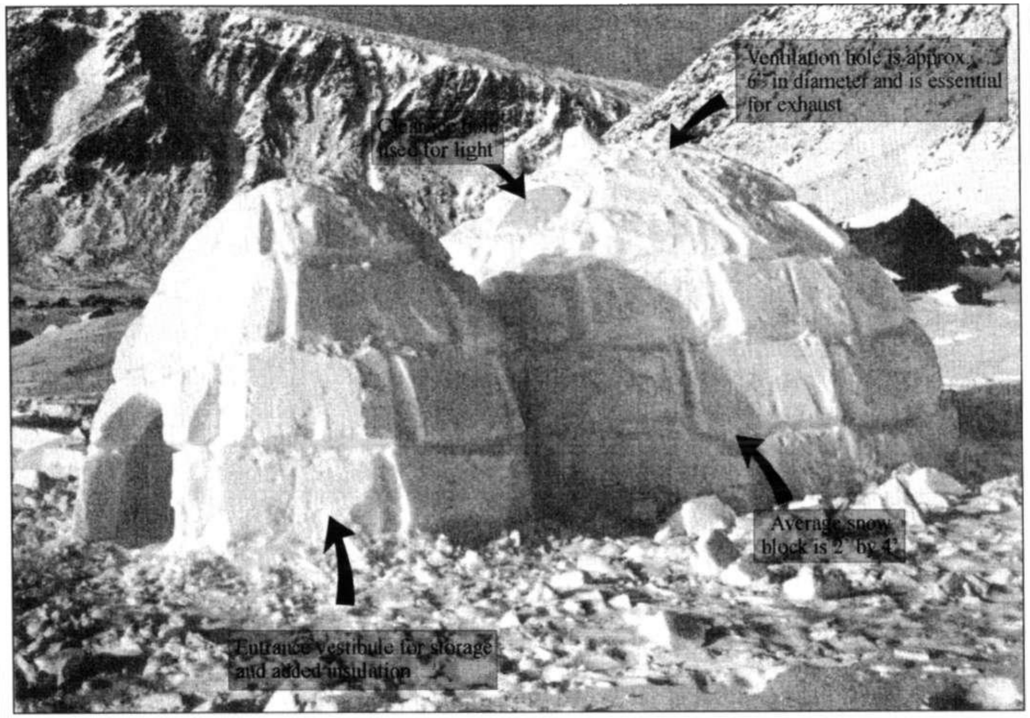
Location:
Througout Canadian High Arctic

Season of Use:
Winter

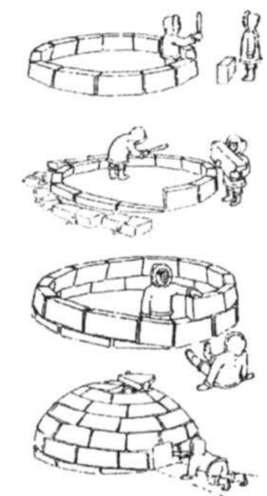
Designer/Architect:
Owner

Primary Building Materials:
Snow
Animal Hide

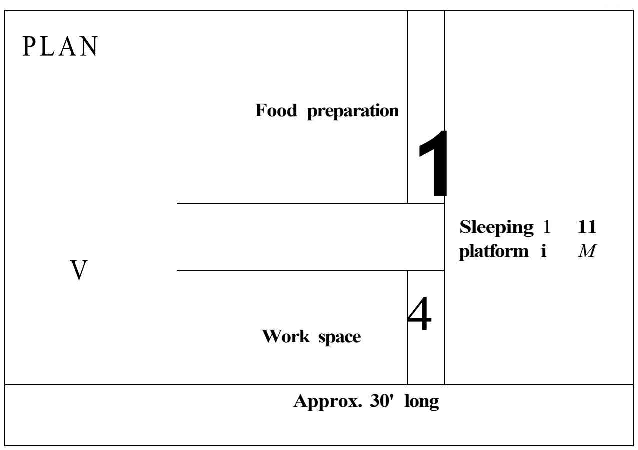
Origin of Materials:
Local



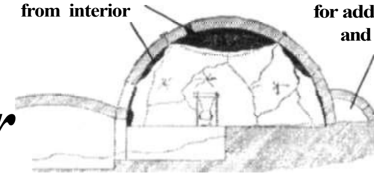
DETAILS



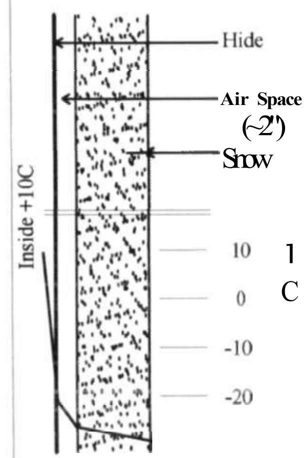
PLAN



BUILDING SECTION



WALL SECTION



WHALEBONE HOUSE

SPECIFICATIONS

Date of Construction:
circa 1500 A.D.

Location:
Bathurst Island, NWT

Season of Use:
Winter

Pesigner/Architect:
Owner

Primary Building Materials:
Whalebone
Sinew
Sod
Hide
Snow

Origin of Materials:
Local

Modem reconstruction of whale bone house

Mandible used as central beam

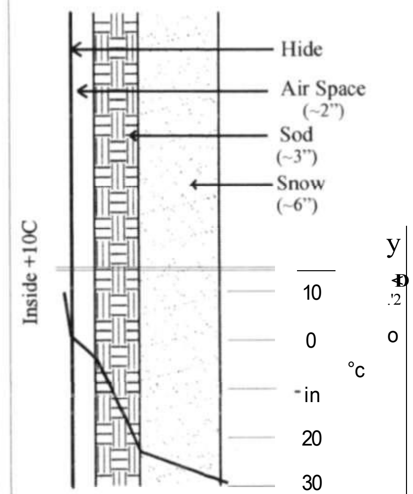
Archaeological remains of collapsed whale bone house

DETAILS

- **Up to 15 individual whales could be used to build one large house**
- **Seasonal and generation re-use of building materials was the norm**

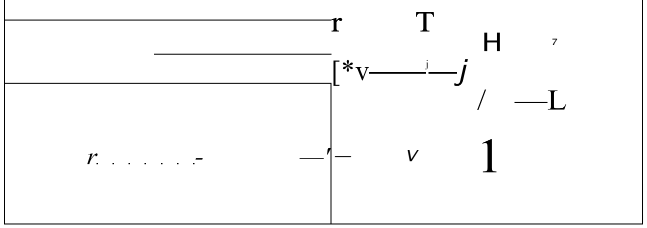
A mandible is longer than a full-grown man

WALL SECTION

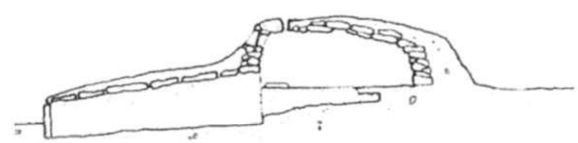


Thermal Gradient

PLAN



SECTION



COLDSTR.EAM HOUSE

SPECIFICATIONS

Date of Construction:
1983

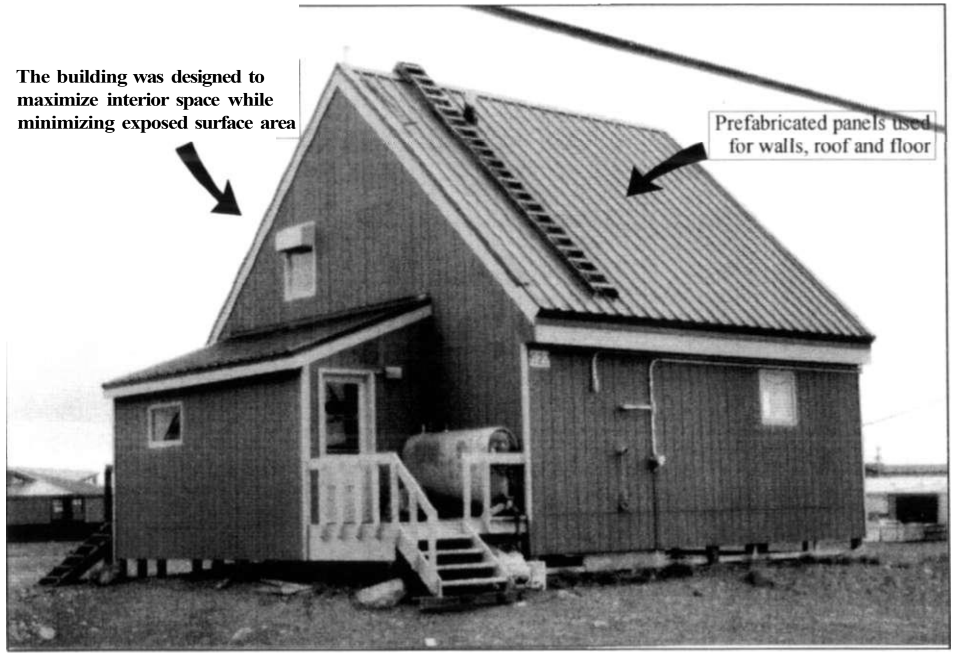
Location:
Arviat, Nunavut

Season of Use:
All Year

Designer/Architect:
#10 Architectural Group

Primary Building Materials:
Sheet metal
Polyurethane Foam
Wood

Origin of Materials:
Non-local



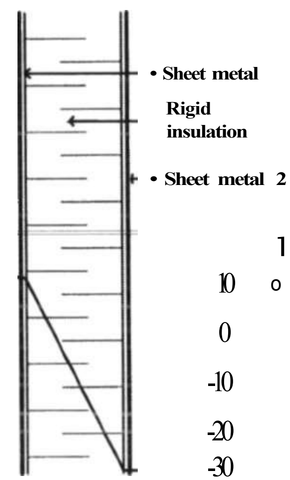
DETAILS

Cost per unit: $130,000

Panels were bolted to a stiff timber frame

Only 24 units built before production was stopped

WALL SECTION



Thermal Gradient

PLAN

SIDING KITCHEN

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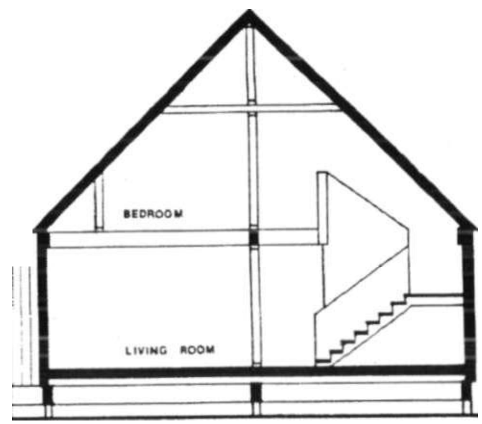
COLD STOfiXCE

SECTION



CHAPTER. 6: ANALYSIS

BUILDING SCIENCE ANALYSIS OF THREE BUILDINGS

The previous chapter described and discussed Arctic construction from a historical perspective, discussing the earliest building first (Whalebone house, circa 1500AD) and progressing through the eighteenth century (Snowhouse, circa 1900AD) to the most recent example of Arctic construction (Coldstream house, circa 1984AD). This chapter however, will analyse the buildings from a building science perspective based upon the number of materials in the construction of each building. The analysis will therefore, first investigate the snowhouse, with the fewest number of materials, followed by the whalebone house and the Coldstream house. While this methodology disregards the general historical trajectory common in many analyses, it emphasizes the materials, components and construction methodologies of each building and clarifies the analysis from the building science perspective. The design and construction information central to understanding each building has been presented in section 5.3 of Chapter 5. While the analysis below will make reference to this information, a complete description of design details is not included in this chapter. Furthermore, to expand understanding of the topic, information in each section of the analysis has been cross-referenced to other sections of the analysis. While this emphasizes the information that is presented, it also serves to illustrate how the component parts of the analysis are interconnected.

6.1 ANALYSIS: SNOW HOUSE

6.1.1 FORCES EXIST TO ACHIEVE A BALANCE

Question: What are the forces at work in, or on, the building? How do they attempt to achieve a balance? Will achieving this balance affect the stability, durability, or commodity of the building?

The forces that are at work on the snow house are numerous. As the building is often primarily a shelter from the incessant wind on the open arctic plains, wind pressure differences will play a major role. As the air pressure attempts to equalize across the building envelope, there will naturally be a negative pressure on the inside of the building that will attempt to equalize with the outside environment. Similarly, temperature and humidity differentials across the building envelope will try to equalize.

Stability - Air pressure differentials can be powerful forces against any building. However, in order for this to occur, the enclosure must be airtight. While hard-packed and chinked snow does have the capability to be airtight, there is a ventilation hole at the top of the enclosure that will prevent any pressure buildup. As such, the equalization of air pressure will not likely affect the stability of the building. Temperature equalization across the building envelope however, will eventually have adverse effects on the stability of the snowhouse. The migrating heat from the inside to the outside (see 6.1.3-6.1.5 for a complete discussion) will eventually melt the snow, rendering it incapable of maintaining its structure, and jeopardize the stability of the building. Finally, humidity levels within the building will not affect the structure of the building as any moisture would condense on the hide, thereby not affecting the structure of the snow.

Durability - Because the equalization of air pressure across the building's enclosure is not likely to have any adverse effects on the structure of the building, the durability of the building is not in danger. In the same way, temperature equalization, although it will eventually destroy the building, in most instances does not reduce the durability of the building. Because the intended use life of the structure is usually a short period of time (two days to two weeks), by the time any the building has fallen in, the intended use-life has expired. Indoor humidity levels similarly would not affect the durability of the building. If excessive indoor moisture condenses on the hide, a layer of frost may form, or may fall on the occupants. This does not affect how the building protects the occupants, or have an affect on the durability of the building itself.

Commodity - There is a very low commodity investment in the construction of a snowhouse. Using materials found on site and necessitating very little processing before use, the snowhouse can be constructed in as little as two hours. An awareness of the effects of temperature equalizations on the integrity of the building is apparent, as the occupants invested little time, energy or resources in the construction of the building. Similarly, the building is not used for a long enough period of time for a significant amount of condensation to build up on the interior, thereby jeopardizing the building.

6.1.2 THERE IS ALWAYS A POINT OF DIMINISHING RETURN.

Question: With most design decisions, there is a point of diminishing return. Have the design decisions that have been made maximized the potential of the materials, components and systems? How do these decisions affect the stability, durability and commodity of the building?

Modern studies of the construction and use of the traditional snowhouse have focussed incessantly on details. Investigations of optimal wall thickness and snow type have dominated these experimental investigations. In reality however, the Inuit did not measure the snow blocks before using them, and they did not consult thermal coefficient information before deciding on wall thickness. As such, any analysis of this building type must be kept at a general level. We must therefore couch our observations in a more broad context. For example, snow is an excellent insulator. If you create thicker wall by adding more snow, it will have greater insulative properties. However, there comes a point where the insulating return is not worth the investment in time and labour to add the material, and the additional weight could affect the structure of the building.

Stability - The point of diminishing return is obvious when investigating the snow load. There is a point where putting on more snow for more insulative capabilities will render the structure unable to support itself. On the other hand, a thicker wall/roof system could make the building stable for a longer period of time in the face of migrating heat and melting walls. These design decisions have a further impact on the amount of labour necessary, and the time needed to construct the building. These are the factors and trade-offs that must be considered to affect the stability of the snowhouse.

Durability - If the thickness of the walls is increased, this could have a positive effect on the durability of the building, as thicker walls will not melt as quickly as one with less snow. The trade-off is that the stability of the structure is compromised by the increased weight of the additional material, which may severely compromise the durability of the structure and may cause the building to collapse under its own weight.

Commodity - It is clear that the Inuit have assessed how to maximize the potential of the building materials at hand with the length of time that they intend to occupy the building. As such, it is likely that each time a snowhouse is built, the localized conditions and specific circumstances of the construction would allow them to make decisions to optimize their construction potential for the commodity input.

6.1.3 HEAT TRAVELS FROM THE HOT TO THE COLD

Question: Does the heat travel from the inside to the outside of the building, or vice versa? How will this heat flow affect the stability, durability, and commodity of the building?

The snowhouse is a seasonal dwelling that is built only during the winter months in the Canadian High Arctic. The occupants strive to stay warm inside the building, separate from the cold and harsh exterior environment. The heat generated inside the building will therefore migrate to the colder exterior.

Stability - The fact that heat migrates from the interior to the exterior will inevitably have an adverse effect on the stability of the snow house. As heat migrates through the wall, which is comprised of compact snow blocks, it will naturally melt the snow and ice. As the interior space is occupied for longer periods of time, the walls of the snowhouse will start to melt. One benefit is that the low ambient air temperature outside will help to neutralize or slow these effects. Ultimately, however, the snow will loose its stability and the building will collapse.

Durability - The Inuit of the eighteenth century were primarily a nomadic people, travelling with migrating herds of land and sea mammals. Most snowhouses were often built only to last from several days to a few weeks. Accounts from explorers and other people who documented snow houses tell of the walls dripping as they melt after several days which inevitably lead to the structure caving in. As the snowhouse was meant to be no more than a shelter for a short period of time, the building was indeed durable. In cases where larger snowhouses were built with an intended use-life of longer than two days, construction took longer, and the walls took longer to melt.

Commodity - Construction of a small snowhouse can take as little as two hours for two people. The only tool needed is a snow knife, and the only material needed is snow. As a result, there is very little investment of man-hours or resources to construct such a building. Larger snowhouses naturally take more time and man-hours to construct. But the overriding consideration by the occupants is that the building will not last for a long period of time, and thus there is always a relatively low commodity investment in snowhouses.

6.1.4 THE GREATER THE DIFFERENCE IN TEMPERATURE, THE GREATER THE HEAT TRANSFER

Question: Will increased heat transfer through the building envelope affect the stability, durability, and commodity of the building?

Heat is generated inside a snowhouse in two main ways: from people (and occasionally dogs) and from the *kuliq,* a stone lamp that burned seal fat. While the *kuliq* provided a small amount of heat and light, the presence of people in the snowhouse contributed significantly to the heat needed to live comfortably. There are accounts of the temperature reaching such extremes that the occupants had to remove their heavy winter clothing to get cool. Therefore, while the temperature outside the building fluctuates according to weather conditions, so to did the inside temperature, depending on the number of occupants and the occupant activities. The end result is a greater temperature difference across the building envelope.

Stability - Snow was originally used in the construction of a snowhouse for many reasons, not the least of which is that it is a good insulator. If there is greater discrepancy between the temperature inside and outside the building, heat will naturally flow through the walls and roof at an increased rate. This will logically result in an increased rate of melting. Therefore, it is likely that the stability of the structure would be in jeopardy earlier due to the increased amount of heat migrating through the walls and roof.

Durability - With increased heat flow through the walls and roof of the snowhouse, there would have naturally been an increased rate of melting and deterioration. As a result, the building would have begun to melt and degenerate more quickly, thereby reducing its durability and decreasing its use life.

6.1.5 HEAT CONDUCTION WILL ALWAYS OCCUR

Question: What efforts have been made to slow the conduction of heat through the building envelope? How do these efforts affect the stability, durability, and commodity of the building?

Snow is an excellent insulator. This is evident in its composition of snow particles (or flakes) with air between each, which slows heat flow by conduction. Because of differing conditions when snow falls and as it settles on the ground, snow can be either hard packed or light and fluffy. Although the former is more conducive to being used as a building material, its dense nature makes it less thermally efficient. Therefore, the Inuit would often line the inside of the snowhouses with animal hides, creating a thermal air space, and at the same time preventing the melting walls and roof dripping onto the occupants. This served to further insulate the interior space and create a buffer zone between the hide and the interior of the wall, thereby sheltering the snow walls from the immediate heat.

Stability -The interior hide lining was mechanically attached to the snowhouse walls and roof by way of toggles that extended through the wall and were secured on the outside surface of the building. As this is simply an attachment to the original building, it in no way affected the stability of the structure.

Durability - The simple addition of the hide lining to the interior of the snowhouse served to dramatically extend the use life of the building. Without the liner, the hot air generated inside the snowhouse would come into immediate contact with the snow walls and roof. This would eventually lead to the melting and deterioration of the building. But with the liner in place, the warm air would be held in the main occupied cavity of the snowhouse and a colder air space would be created between the liner and the snow wall/roof. Therefore, it would take longer for the heat to migrate to the snow wall/roof, and increase the use-life and durability of the building.

Commodity - Upon initial investigation, the simple installation of the hide liner to the building would appear to have an incredible return for an insignificant amount of time and labor, as it appears not to be a time-consuming or resource heavy task. However, on closer inspection, the hide itself is a valued resource, necessitating great labor to acquire, process and continued energy to maintain and transport. Used for both summer and winter dwellings, the hide therefore represents a large embodied commodity, the return of which is evident in the increased thermal performance of the snowhouse.

6.1.6 MATERIALS WILL NOT DETERIORATE IF ONE OF THE CONDITIONS FOR DETERIORATION IS ABSENT

Question: What are the conditions for deterioration of the materials in the building? Which of these conditions are present? How will these conditions affect the stability, durability and commodity of the building?

The main building material used in the construction of a snowhouse is snow. As such, there appears to be only one condition necessary for deterioration: heat. As discussed in section 6.1.4, heat that is generated within the structure can elevate indoor temperatures well above 90°F. Therefore the one condition for deterioration, heat, is indeed present, and is inherent in the occupation of the building. Heat from the sun that warms the air temperature can also be a problem, as is the case in the late spring, when temperatures regularly rise above the freezing point.

Stability - As discussed in sections 6.1.2-6.1.4 above, deterioration due to the presence of heat will affect the stability of the snowhouse by deteriorating the snow and collapsing the structure.

Durability - Although heat is present in the building, and will cause the deterioration of the building itself, this appears to be the determining factor in the intended use-life of these buildings. Historical accounts of the snowhouse regularly discuss how the roof dripped water as it melted, and how old snowhouses that had caved in could be seen on the landscape. Regardless, the snowhouse is a durable building given its short intended use-life.

Commodity - It is inherent in the very use of the snowhouse that heat will exist within the building. It is therefore inevitable that it will deteriorate due to melting from the heat. It seems that the builders/occupants clearly understood this and took this under consideration in construction, and ensured that very little commodity was invested in the building. As snow is an ample resource, readily available on the landscape, and construction of a snowhouse could take as little as two hours, there was relatively little commodity investment in the building.

6.1.7 MATERIALS MUST HAVE SUFFICIENT TIME TO CURE UNDER OPTIMAL CONDITIONS

Question: What are the main materials in the building? What are the optimal curing conditions that would be required? If they were not cured properly, would this affect the stability, durability and commodity of the building?

The main building material of a snowhouse is snow. Although snow exists in many forms (light and fluffy or hard and sticky), it is essential that in the construction of a snowhouse, only hard-packed snow be used. This snow must be harvested in blocks from a drift that was formed during a single snowstorm, and the snow must be fine grained. Snow in a drift that has been formed over several storms will have layers of stratification, and the block will tend to break along these lines. Therefore the snow used in the construction of a snowhouse must be laid down in optimal conditions.

Stability - It is imperative that hard packed, uniform snow be used in the construction of any snowhouse. As there is no underlying support structure on which the snow rests, the snow itself is the structure of the building. Each block is set on top of another, and leans on the adjacent block for support. If snow is used that is not compact, or has inconsistencies within the snowdrift, this could jeopardize the stability of the snowhouse. Construction of the conical structure depends solely on the snow blocks resting on one another as they spiral upward. If the blocks are faulty, the building will be unstable and possibly even unbuildable.

Durability - Although the snowhouse is meant to have a very short use-life, the building can still be deemed to have poor durability. If inferior quality snow is used in the construction of the building, and this results in premature deterioration (ie. the walls fall in after one day, and the building's intended use life was three or four days), then using improperly cured building materials will greatly affect the durability of the building.

Commodity - Although there is generally low commodity investment in a snowhouse, the investment is still essential to the construct the building. As such, using materials that have not been properly cured will jeopardize any investment in the construction of the building.

6.1.8 MOISTURE CAN CHANGE THE PROPERTIES OF MATERIALS

Question: How will moisture affect each building material? How will these properties affect the stability, durability and commodity of the building?

Moisture can take one of three forms: solid (ice, snow), liquid (water) or gas (vapour). Although snow is inherently a material made of moisture, it is not precluded from changing in the presence of moisture as a liquid or gas. If water (moisture in a liquid form) were to come in contact with the snow, it will do one of two things depending on the ambient air temperature. If the ambient air temperature is on the warm side, the water will melt the snow, as water is naturally above the freezing point, and the snow will turn to water. If the air temperature is very cold, the water will melt the snow and immediately freeze and turn to ice. As water vapour moves across the surface of the snow, sublimation (the transformation of moisture as vapour directly to a solid form) will occur and a thin sheen of ice will form on the surface. While this does change the thermal properties of the snow, it also serves to add weight to the snow structure. However, when considering the inherent changes in the presence of water, water vapor has a less significant impact on the snow. In any instance, moisture in any form, except snow itself will change the properties of the snow.

Stability - If moisture in a liquid form (water) were to come in contact with snow and partially or completely melt it, then the walls and roof of the building would dissolve, the very structure and stability of the building would disintegrate. If the water melts the snow and then turns to ice, the thermal properties of the walls/roof would be significantly changed, as ice conducts heat more efficiently than snow. Again, ice formation would add significant weight to the structure, and may seriously affect the stability of the building.

Durability - Clearly the durability of structure is severely compromised when snow is exposed to water. In jeopardizing either the structure or the thermal efficiency of the building, the use-life is shortened and the durability of the building lessened.

Commodity - There is at least one sure thing during most of the year in the Canadian High Arctic: due to the average below freezing temperatures, moisture rarely occurs as water. As such, the Inuit continued to invest time, labour and materials in the construction of snowhouses, even though water can expediently destroy the building. This is therefore not perceived to be an imminent threat. If it were, the risk of destruction would likely be too great to continue to build with this material.

6.1.9 MATERIALS CAN CHANGE DIMENSION WITH TEMPERATURE CHANGE

Question: How do the materials react to changes in temperature? How will this affect the stability, durability and commodity of the building?

Most modern building materials will contract when exposed to cold and freezing temperatures and expand when exposed to heat and warm temperatures. By contrast, snow remains relatively inert in the cold or when inflicted with colder temperatures (obviously as the presence of snow denotes a temperature below freezing), and will contract and shrink in warmer temperatures. This latter statement gives the impression that the material will essentially remain the same, but simply contract in a warmer environment (as is the case with many modern materials). In fact, the apparent "contraction" is the melting of the material. While most other building materials will expand and contract and eventually return to their original form, snow will turn either to water or refreeze into ice. It will under no circumstances return to its previous state. Another important point is that any temperature fluctuations within the range below the freezing point will not significantly alter the dimensions of the material. Likewise, temperature fluctuations in the range above freezing are for the most part irrelevant, as the material itself will cease to exist. The significant temperature range therefore is a few degrees above and below freezing, where phase changes can dramatically affect the nature of the building material.

Stability - If the snow blocks of a snowhouse are subjected to extreme temperatures below zero, the stability of the building will not be jeopardized, as any change in dimension that might occur from the cold environment will be negligible and will not jeopardize the stability of the snowhouse. On the other hand, as the temperature approaches and rises above freezing, the dimensional changes, due primarily to a phase change in the material, will undoubtedly affect the stability of the building, as the structure itself will melt away.

Durability - Clearly a severe temperature fluctuation will drastically affect the use life of a snowhouse. However, this type of building is only constructed and used during the winter months. As such, for the conditions that consistently remain below freezing, the snowhouse is a durable building type.

Commodity - Inuit snowhouses are built and used only during the winter months, which are characterized by average daily temperatures well below freezing. As such the commodity investment in a building with an impermanent construction material is logical. For the majority of the winter, they do not have to worry about dimensional change due to temperature fluctuations (except as a result of heat generated within the building itself - see 6.1.3-6.1.5 above for a full discussion)

6.1.10 THE WEAKEST MATERIAL WILL FAIL FIRST

Question: What is the strongest material in the building? What is the weakest material? If the weakest material was to fail, how would this affect the stability, durability and commodity of the building?

There is only one main material used in the construction of the snowhouse: snow. As such, it is not possible to compare it to an adjacent material that is either stronger or weaker, or to assess its relative role in the maintenance of the building. If the only material in the building were to fail, it would obviously affect all three of the functional requirements of the building. There is a serious drawback to constructing a building of only one material.

6.1.11 NO MATERIAL IS INFINITELY STRONG

Question: What will affect the strength of the building materials? Will this affect the stability, durability and commodity of the building?

There are many foes to snow that have been discussed in the analysis of the snowhouse. While snow in its frozen state has remarkable strength, heat and moisture, in changing snow to water of ice, have the potential to render its strength ineffective, the material useless, and the building itself nonexistent.

Stability - Clearly, both heat and moisture will affect the properties of snow that provide it its characteristic strength. As the strength of the material is compromised, so will the stability of the building be placed in jeopardy. The snowhouse itself remains standing and enclosed because of the strength of the snow blocks to support one another. If this strength is threatened, then the very stability of the structure is similarly endangered and the building will likely collapse on itself.

Durability - When conditions arise that affect the strength of the material in a snowhouse, the durability of the building is greatly affected. In having a building with such a short intended use-life (2 days to a few weeks), it seems likely that the weaknesses of the material have already been considered and factored into the expectations that the Inuit have of their building. Two days is not a long period of time, and it appears that the builders were aware of this when they designed and anticipated how long to use the snowhouses.

Commodity - In a similar way to the comments on durability it appears that the Inuit were fully aware of the limitations of the snow and how it functioned as a building material. Very little commodity investment was endowed in the construction of a snowhouse. This is immediately understandable in light of the many factors that could affect the strength of snow, the primary, and only, material in the construction of the building.

6.2 ANALYSIS: WHALEBONE HOUSE

6.2.1 FORCES EXIST TO ACHIEVE A BALANCE

Because of the similar climate and geographical location, the forces at work on the whalebone house are similar to those of the snowhouse: wind and air pressure, temperature, gravity and humidity, All of these forces are constantly attempting to achieve a balance across the building envelope.

Stability - Air pressure differentials across the building envelope can quickly compromised the stability of a building if there is no way for the air to equalize. Inherent in the construction of the whalebone house is a ventilation hole in the ceiling to allow for smoke to escape. Therefore, air pressure changes caused by wind would not likely affect the stability of this building. Temperature equalization across the building envelope will similarly not affect the stability of the building. Migrating heat could eventually melt the snow and soften the sod, and causing them to sump or fall away from the structure. In this instance however, the materials are used mainly for insulative purposes, and do not contribute to the structure itself. Finally, higher humidity levels within the building would not likely affect the structure and stability, as the humid air (likely to be greater than 35%RH) would condense on either side of the hide, not affecting the structural elements.

Durability - Because the equalization of air pressure across the building enclosure does not generally have an effect on the building, this force will not affect its intended use-life. Temperature equalization will eventually have an effect on the building envelope. Central to the use of the building as a shelter are the insulative properties of the sod and snow, and migrating heat will eventually change those properties (ie. melt the materials). By the time this has occurred, however, it is likely that the occupants would have moved to their summer seasonal dwellings. Therefore, because the thermal properties of the sod and snow must only be sustained during the winter months, the durability of the building would not be compromised by their seasonal deterioration. High humidity levels within the whalebone house similarly would not affect the durability of the building. Although condensing moisture would likely form as frost on the interior lining of hide, this would not affect the seasonal use life of the building itself.

Commodity - The commodity investment in the construction of a whalebone house is more significant than the snowhouse because the Inuit intended to use it for six to eight months every year. Therefore, the building itself is able to better withstand the pressures of air, temperature and humidity equalization. It is evident in the construction of the building that the builders knew that although heat would migrate through the envelope, the rate of migration coupled with the extreme exterior environment, would not compromise the building until the season had changed. A structure comprised of several materials that required acquisition and curation represents a large commodity investment. This clearly is to the benefit of the building occupants and the intended use life of the building.

6.2.2 THERE IS ALWAYS A POINT OF DIMINISHING RETURN^

Stability - Like the snowhouse, the point of diminishing return is evident when observing the load that the building envelope exerts on the whalebone structure. The envelope composition clearly allows for its occupants to inhabit a comfortable interior environment, separate from the exterior climate. If the building were made more robust, this would increase the thermal capacity of the envelope and increase occupant comfort. However, there would be a point where the envelope could not be further thickened without affecting the ability of the whalebones to support the building itself. This would naturally compromise the stability of the building. These were the issues that the Inuit builders likely considered when designing and building their winter dwellings.

Durability - The design and construction decisions that have been considered by the Inuit people have clearly been maximized to ensure the durability of the building over the winter season. The decision not to overload the structure and preserve the whalebones was imperative to their survival in the next winter season, as the whalebone structure of the house was used for many years, and could be transported to new locations. Understanding the dynamic relationship between elements of the building ensured the durability of the building.

Commodity - The whalebone house is a clear example of an understanding of how to maximize materials and building composition with inhabitability. The commodity investment in both the building materials and the construction was maximized by the understanding of how a trade-off of one can benefit the other.

6.2.3 HEAT TRAVELS FROM THE HOT TO THE COLD

The whalebone house was a seasonal dwelling that was built for use during the winter months in the Canadian High Arctic. The occupants strove to stay warm inside the building, separate from the cold and harsh exterior environment. Therefore, any heat that was generated inside the building would have migrated to the colder exterior.

Stability - As heat migrates through the building envelope from the interior to the exterior, it will not likely have an effect on the stability of the building. The structure of the whalebone house is based on the framework of the whalebone elements (rafters and cross bracing), which will not be affected by the transfer of heat through the wall.

Durability - The two materials in the composite wall system of a whalebone house that could be adversely affected by heat would be the sod and the snow. If enough heat transferred through the sod, then it is possible that any moisture in the material could melt and as it drains, carry away some of the soil matrix. Similarly, if enough heat is transferred through the snow, or heat transfer has occurred for a long period of time, the material will begin to melt. If one or both of the materials begin to deteriorate before the end of the winter season, then the integrity of the building will be compromised and the original building will not have been durable for the intended use life of the building.

Commodity - The construction of a whalebone house would have taken two to three weeks. The building is intended to last for the winter season, and the commodity investment of materials and labour in construction clearly reflects this extended seasonal use-life. Therefore, the investment in the construction of the building is not greatly influenced by the heat traveling through the envelope, because by the time significant melting of the material would have occurred (usually at the end of the season), the building would have been at the end of its seasonal use-life. Therefore, the commodity investment would not have immediately been compromised.

6.2.4 THE GREATER THE DIFFERENCE IN TEMPERATURE, THE GREATER THE HEAT TRANSFER

Methods of generating heat within the whalebone house are very similar to those employed by occupants of the snowhouses: oil lamps and people. More lamps would be used if more people were inside the building. Therefore, the amount of heat within the building would fluctuate, naturally causing greater or less heat flow across the building envelope.

Stability - As heat transfer will not affect the structure and stability of the building, an increased rate of flow would similarly have no affect on the stability of the whalebone house.

Durability - Increased heat flow would undoubtedly affect the durability of the building. Irregardless of the cold outdoor temperatures, increased heat flow through the envelope would accelerate the deterioration of the snow and sod, rendering the enclosure thermally inefficient and reducing the comfortable use life of the building. The usability of the building for the entire winter season would be jeopardized, and the durability would be compromised.

Commodity - If there was an increase in heat flow though the enclosure, then the building would prematurely deteriorate, thereby jeopardizing the building, and the investment embodied in the construction of the building.

6.2.5 HEAT CONDUCTION WILL ALWAYS OCCUR

Stability - The sod and snow both function to thermally insulate the interior space of the whalebone house. Although the structural stability of the building is attained mainly from the whalebone superstructure, the increased mass of the enclosure as a result of the thermal materials, serves to add stability of the overall unit.

Durability - Although the whalebone superstructure serves to create a strong and durable form, in itself this building material provides very little protection from the external environment. With the addition of the materials that constitute the thermal mass of the building (snow and sod), the building is able to take on the form necessary for comfortable occupation of the harsh Arctic environment. Furthermore, these specific materials enable the building to be occupied for the duration of its seasonal use life, giving it the durability necessary to survive a harsh arctic winter.

Commodity - Both the curation of construction materials and site preparation are what comprise the bulk of the commodity investment in the whalebone house. When compared to the energy expended to acquire and keep the whalebone, sinew and hide, the investment in curating snow and sod are relatively small. Although as essential to the building as the former elements, the amount of time and labour necessary for them to become part of the building is significantly less. Therefore the commodity investment of the thermal materials is significantly less that than those of other areas of the building.

6.2.6 MATERIALS WILL NOT DETERIORATE IF ONE OF THE CONDITIONS FOR DETERIORATION IS ABSENT

The main materials used in the construction of the whalebone house are the thermal insulators (snow and sod), the structure (whalebone and sinew) and the animal hide. Essential to the snow and sod performing their intended function is the maintenance of a frozen state. Therefore, heat (or any other condition that would change the temperature of the material) will be the condition under which these materials would deteriorate. The structural elements, bone and sinew, are both extremely durable materials and have been known to last in the archaeological record for thousands of years. As the soil conditions in the Arctic are not known to be acidic (one of the few conditions to deteriorate bone), it is unlikely that significant deterioration would have occurred. Finally, animal hide is a resilient material that is used extensively in past and present Inuit culture. Factors such as extended use and fire may serve to deteriorate the hide.

Stability - As discussed in section 6.1.3, heat will not affect those elements of the building that are essential to structural stability: whalebone and sinew.

Durability - The climatic conditions of the Canadian High Arctic are extreme and every element of the building (ie. structural or thermal) is essential to the survival of the occupants and the durability of the building through the winter season. As the presence of heat is inherent in the use of the structure, deterioration of the snow and sod would render the building unprotective from temperature extremes and therefore unusable. Acidic conditions that might affect the whalebone and the sinew are not generally present in the arctic. In the case that the building was built in particularly acidic soil, the bone elements might be affected, although this would not likely affect the durability of the building as only the base of the elements (which are usually the thickest) would be affected, and these would not immediately compromise the building's ability to protect for the season. Finally, extended use of the animal hide could render it thin or weak in some areas. This could drastically affect the durability of the whalebone house as the hide is essential to maintaining the form of the building's wall system.

Commodity - As discussed in sections 6.1.3-6.1.5, the effects of heat on the snow and sod would be detrimental to the building and would greatly jeopardize the invested labour in the building. However, the Inuit builders were likely well aware of the limitations of their materials in various conditions (ie. seasons or temperature differences) and maximized use of them during the winter months. Although deteriorating conditions for whale bone and sinew might have existed, the rate of deterioration and unlikelyhood of exposure rendered these materials worth while construction elements. The invested time and labour in their acquisition and curation far outweighed the detrimental effects of deterioration. Finally, the animal hide, which is central to the construction of the entire building, is a durable material and will likely only deteriorate naturally from extended use, in which case it would no longer be of use as a building material. The commodity investment in this material would undoubtedly have been worthwhile as the initial acquisition and curing would have ensured a long use life and beneficial commodity investment.

6.2.7 MATERIALS MUST HAVE SUFFICIENT TIME TO CURE UNDER OPTIMAL CONDITIONS

The following is a list of the main materials in the whalebone house and their optimal curing conditions:

- Whalebone: This material is acquired directly from the carcass of a baleen whale. Historical accounts of Inuit whaling and bone-use confirm that the bones are expediently used with no intentional curing process.

- Sinew: Sinew can be acquired from many land and sea animals that were commonly hunted by the Inuit. In order for the sinew to become pliable and durable, it is reported that the material was chewed by the Inuit to make the material soft and pliable.
- Sod: Central to the sod being used as a building material is its ability to remain as a coherent unit (ie. a solid block of soil versus crumbly loose soil). This is accomplished when the sod is in a semi-frozen or frozen state. Because permafrost (see chapter 5 for a discussion of permafrost) exists year round and extensively throughout the Canadian High Arctic, this material is naturally occurring, available in abundance and requires no curation before use. It is essential, however, that the material be acquired at a very specific time of the year: the early fall season, when the ground is not frozen solid (and therefore is not too hard to be cut), yet frozen enough to still hold the form of a block.
- Snow: Much of the evidence and information pertaining to the construction of a whalebone house is courtesy of archaeological investigation and historical accounts. Unfortunately, these have focused on the other more unique elements of construction than the omnipresent snow. However, when reflecting upon the requirements of the snow in a snowhouse, it can be ascertained that the whalebone house would necessitate similar uniform and hard-packed qualities. Although the material is not used in a structural capacity, it would need to have sufficient ability to remain in a vertical application and withstand the corrosive forces of the

wind. Therefore, it is essential for the builders to have chosen snow that had cured with these properties

- Hide: Animal hides were (and still are) acquired from hunting land animals. The material must undergo an extensive curing process before it is suitable to use in any application. Firstly, and perhaps most importantly, all remnants of flesh must be removed through scraping and drying of the hide. Further disinfection occurs with extensive exposure to the suns cleansing rays that will degenerate any animal matter before it turns rotten and corrosive to the material. Secondly, the hide is then extensively conditioned with saliva (Inuit women will chew on the hide thereby saturating it with saliva, which serves to soften the material, making it more pliable). Both aspects are essential to the preparation of the hide.

Stability - Of the structural elements needed to maintain stability of the building, only the sinew requires specific and optimal curing conditions. If this material were not prepared correctly before use, then the sinew would dry out and/or freeze, become brittle and break. Because this material is essential to the whalebone elements forming a surrounding structure, not preparing this material properly would undoubtedly compromise the stability of the structure.

Durability - If improperly prepared sinew were used in the construction of a whalebone house, the durability of the building would naturally be affected as it would unlikely remain intact for the duration of its intended use-life. Similarly, if sod and snow that were not cured properly were used in a building, the protective layers of the building would be deteriorate, and the building would eventually be unoccupiable, and therefore not useable for its intended use-life. Finally, if the hide was not cured properly before used, the flesh remains could go rancid, rotting the fabric of the material and creating a stench for the occupants. Furthermore, the material would be too stiff to wrap around the whalebone structure, and would become brittle in the cold temperatures of an Arctic winter. This would affect the durability of the building as the hide is essential to maintaining the composition of the walls, and the comfort of the occupants.

Commodity - There is a significant commodity investment in the acquisition and curation of the building materials for a whalebone house, and it is obvious that the Inuit were aware of the investment required in order for their materials to function as part of the building enclosure. Using even one material that has not been adequately prepared could jeopardize the commodity investment in the entire building.

6.2.8 MOISTURE CAN CHANGE THE PROPERTIES OF MATERIALS

As discussed in section 6.1.8, moisture in any form (solid, liquid or gas) can have an affect a building material. Although during the winter months in the Canadian High Arctic, moisture rarely occurs for a long period of time as anything other than a solid form (generally ice, snow or frost). The composition and construction of the whalebone house relies heavily on the maintenance of these freezing conditions. Therefore, contact with moisture in any other form (liquid or gas) generally denotes an increase in temperature which can be detrimental to several of the building materials, namely the sod and the snow (see sections 6.2.3-6.2.5 for a full discussion). The durable bone and sinew on the other hand are not likely to be affected by exposure to moisture in any form. Prolonged exposure of the hide to moist (ie. liquid) conditions would eventually deteriorate the structure of the hide rendering it unusable as a building component.

Stability - The presence of moisture in any form will not likely affect the structural components (bone and sinew) of the whalebone house. Both materials are highly durable and would not be affected by the presence of water (due to melting) or frost buildup (vapour condensing and freezing on the members). As discussed in numerous previous sections (6.1.3-6.1.5) possible deterioration of the other elements would not likely affect the stability of the building.

Durability - The presence of moisture in the form of a liquid (water) will naturally have an effect on both the sod and snow. The water, which is inherently a warmer temperature will serve to change the solid, frozen properties of the materials that are necessary for them to function in this capacity. This would affect the durability of the building as it would no longer be able to function for the duration of its uselife.

Commodity - Although there is a significant commodity investment in the construction and curation of a whalebone house, this investment could quickly be discounted with the deterioration of the sod and snow due to the presence of above-freezing moisture. The commodity investment would be jeopardized, as the building would have little thermal protection for the occupants.

6.2.9 MATERIALS CAN CHANGE DIMENSION WITH TEMPERATURE CHANGE

Temperature changes can be characterized as either an increase or decrease in thermal environment. The whalebone, sinew and hide are all relatively stable materials and will likely show no noticeable change in dimension with a fluctuation in temperature. The snow and sod however, will exhibit dimensional changes because of the moisture content inherent in the materials. The soil component in the frozen sod blocks will not itself change dimension. The moisture however, in the sod which renders it frozen will change dimension and melt. As discussed in section 6.1.9, snow, once it has melted, cannot be reconstituted back into snow. Therefore, a temperature change above freezing will be detrimental to this building material.

Stability - The stability of the whalebone house would not be jeopardized by a temperature change as the whalebone and sinew would not change dimension.

Durability - If temperature fluctuations occurred around the freezing point, resulting in the deterioration of the sod and snow, then the durability of the entire building would in jeopardy. Once the snow has deteriorated due to an increase in temperature, the building will no longer be equipped with its protective layer. As the sod melts, it will eventually loose its shape and sump away from the building. This will render the building unlivable in Arctic conditions.

Commodity - The commodity investment in the building would be jeopardized by a significant increase in temperature. As discussed in sections 6.2.3-6.2.5, the entire building would be compromised by the deterioration and degradation of the insulation materials.

6.2.10 THE WEAKEST MATERIAL WILL FAIL FIRST

The primary materials in a whalebone house are the bone structural supports, the sinew lashing, the hide, the sod and the snow. The overall strongest material would be the whalebone, as it is relatively inert and any fluctuations in interior or exterior conditions (i.e., heat or relative humidity) will not likely affect the performance of the material. The snow would be the weakest material in the assembly as there are a number of factors that can affect its integrity (see sections 6.2.3-5 above).

Stability - If the weakest material, the snow, were to fail the stability of the building would not be jeopardized. The role of the snow in the whalebone house is as an insulative and protective layer on the exterior of the building; it has no structural role to play. The building itself would still stand, have stability and provide limited protection to the occupants if the material were not present.

Durability - Whalebone houses were constructed as winter dwellings and were intended to last the duration of the season. If the weakest material, snow, were to fail and stop performing as it was intended (ie. in its frozen "snow" state) in the middle of the season, then the durability of the building could be at risk. The reduced thermal capacity of the walls could render the interior uncomfortable. Furthermore, the less sleek profile of the building would make it more susceptible to the effects of strong and incessant winds. Ther is the possibility that the building would not last the winter season if the protective layer of snow was absent from the building.

Commodity - The construction of the whalebone house represents a significant investment of resources in both time and materials. If the snow layer were to fail (ie. melt or loose its insulative qualities) the building would still continue to function as intended, although with a loss in thermal efficiency. The time and materials that have been invested in the construction of the rest of the building would not be lost. Although the outer sod layer might be prone to deterioration due to wind erosion, its dense nature would protect it and allow it to persevere. When conditions allow for snow to be available again, the material can simply be reapplied to the exterior, and the total investment in the construction of the building will not be lost. On the other hand, if the snow has disappeared due to a seasonal temperature change, then this would have signaled a change in seasons, and a corresponding change to the summer dwelling. Again, this would not adversely effect the integrity of the building, as the intended use-life is only for one season at a time.

6.2.11 NO MATERIAL IS INFINITELY STRONG

The construction of a whalebone house depends on the strength of the bone rafters and the sinew that binds them. Both materials are relatively stable under changing conditions of temperature and moisture. Therefore, it is likely that the one factor that would affect the strength of the materials would be extended use and the fatigue that would naturally ensue. Sinew, although a durable material, will eventually become slack and dilapidated from over-use. Bone, if handled with care, will have incredible longevity, as its hard calcium structure is very durable. If it is handled poorly however, or continuously over loaded, the materials will begin to crack and eventually break.

Stability - If one lashing of sinew in a whalebone house was to loose its strength and fail, it is unlikely that the stability of the entire building would be greatly affected. The strength of the other joints in the structure would compensate and the building would likely remain standing. If however, there was a systemic failure of the sinew, then the stability of the entire structure would be compromised, as the structural rafters and beams would not be bound to one another. There is a similar scenario for bone elements. If a minor cross beam rib were to lose its strength and break, it is unlikely that the stability of the entire structure would be lost. However, if one or more large mandible rafters were to loose structural capacity, then the building could collapse.

Durability - Because the whalebone house is intended to be used for the entire winter season, any breach in the structural materials (sinew or bone) would indicate a failure in the original building system and could affect the remaining use life of the building as a whole.

Commodity - The commodity investment in a whalebone house reflects clearly the intended seasonal use life of the building. The survival of the occupants depends on the durability of the building through the winter months. As a result, enduring materials were chosen for the building, and acquired at great cost over several years. If materials fail, then there is an obvious loss in the commodity investment, However, the materials that were chosen were robust, stable materials, where the likelihood of failure would be small, and the frequency of defects would be very low. All materials have the potential for failure, as no material is infinitely strong. In this case, materials were chosen that maximized material potential to achieve longevity and reliability.

6.3 ANALYSIS: COLDSTREAM HOUSE

6.3.1 FORCES EXIST TO ACHIEVE A BALANCE

The Coldstream House is situated in the same climate as the snowhouse and whalebone house: the Canadian Arctic. As previously discussed, the main forces at work on a building in the Arctic are the following: wind and air pressure, temperature and humidity. These forces are always attempting to achieve a balance across the building envelope.

Stability - Although the design of "modern" housing (i.e. post WWII) often focussed on an attempt to create a completely enclosed envelope, housing of the 1970's and later endeavored to create an air tight building envelope that would completely contain the interior environment. During this time however, there was little attention to connection details, resulting in what we would currently call a "leaky" house, or a situation where air passed freely through the building envelope through unsealed joints or spaces between different materials. Consequently, wind and air pressures equalizing across the building envelope never compromised the stability of the building. Temperature migration similarly would not have affected either the wood frame or the thermal panels. Higher humidity levels would not likely have had an effect on the wood structure because the thermal panels created an fairly effective vapour barrier inhibiting moisture from migrating through the wall.

Durability - Because the equalization of air pressure across the building envelope would not have affected the structure of the building, the durability and use-life of the building would not have been adversely affected. Likewise, temperature equalization would not have affected the building's durability. Because the cavity in the panels was filled with foam, and the dew point is not a consideration, higher humidity levels were not a concern to the durability of the building.

Commodity - The commodity investment in the construction of the Coldstream House is more significant than for the snowhouse or the whalebone house. This is evident in the energy expended in material procurement and manufacture, and building manufacture, transport and assembly. As such, equalization of each of the forces at work on the building would not have jeopardized the commodity embodied in the building itself.

6.3.2 THERE IS ALWAYS A POINT OF DIMINISHING RETURN.

Post WWII design and construction has focussed heavily on the "science" of building which has included optimizing materials and construction methods. The design of the Coldstream house is borne of this era, and specifications such as the wall thickness (and therefore insulation thickness) and interior area of living space versus external surface area of the building were all considerations of the design team. As such, the thickness of the thermal panels (5") was likely a point of intense scrutiny between maximized thermal performance and saving versus the costs of manufacture and transport.

Stability - The choice of a wood frame was likely the most expedient design decision when recognizing diminishing return. A typical wood frame structure was common in house construction of the 1980's as the material was inexpensive, versatile and readily available (in the south where design and manufacture occurred). The material performed well in most instances and would have maintained its structure in the Arctic climate.

Durability - The specific design of the thermal panels is connected to the durability of the building. As one of the original design intents was to have the building last for approximately 40-50 years, the materials and design would naturally have to reflect this. As a result, the use of relatively stable materials at a specified thickness was striving to achieve this.

Commodity - The research, design, manufacture and transport of the prefabricated panels all contributed to the commodity investment embodied in the building. Any specific design decisions would naturally be included in this commodity.

6.3.3 HEAT TRAVELS FROM HOT TO COLD

The most important aspect in dealing with heat transfer is that the external temperature is usually colder than 22EC (average room temperature). Therefore, the general direction of heat flow for most of the year is from inside the building to the outside environment.

Stability - The fact that heat migrates from the interior of the building to the exterior will not have an adverse affect on the stability of the materials that comprise the structure of the building. The wood frame will not be affected by heat migration, and will continue to maintain a stable structure.

Durability - The Coldstream House was meant to last for several decades of continued year-round use. The materials central to this use are the wood frame and the composite wall panels. The wood frame is outside the building envelope and is subject only to a cold and dry climate; its use-life would not have been compromised by any heat transfer. The metal and insulation of the prefabricated panels are relatively inert and would not be affected by heat flow through them. Although they are designed to slow the rate of heat flow, extreme temperatures such as those reached in a fire (not usually attained during normal living conditions) would be required to affect them.

Commodity - The large commodity investment embodied in this building would not be adversely affected by heat flow, as the materials would continue to function as originally designed and anticipated.

6.3.4 THE GREATER THE DIFFERENCE IN TEMPERATURE, THE GREATER THE HEAT TRANSFER

Luxuries of modern convenience, such as controlled indoor heating systems, allow the indoor temperature to be maintained at a constant temperature, ideally thought to be 22EC. As the outdoor temperature naturally fluctuates from day to day and through the seasons, and greater temperature differentials between the indoor and outdoor environment occur, there will be a greater or lesser flow of heat across the building envelope.

Stability - Because heat flow alone will not affect the building's structure, increased heat transfer will also not have an adverse affect on the stability of the building.

Durability - The Coldstream house is designed for the harsh environment of the Canadian Arctic, and as such was designed for the "worst case scenario" of maximum possible heat flow. This will not however affect the building's ability to continue to protect the occupants from the outside environment.

Commodity - As with durability, the building was created to deal with extreme cold. Therefore, the large commodity investment in the building is naturally reflected in its ability to deal with temperature differentials.

6.3.5 HEAT CONDUCTION WILL ALWAYS OCCUR

Inhibiting the flow of heat by conduction is central to the design of most buildings in the north. In the Coldstream House, the wall panels themselves have been designed to slow the conduction of heat and insulate the interior space.

Stability -Heat conduction will not likely affect the wood structure of the building, because the structural integrity of the material is not greatly affected by variations in temperature.

Durability - Attempts within the design of the building to slow heat conduction contribute significantly to the durability of the building. The use of relatively inert materials that are not affected by temperature change and variation allows the building to be used for the extended use life for which it was designed.

Commodity - The design of the wall system alone reflects a large commodity investment, not in only materials and labour, but also research. All attempts to reduce heat conduction (most of which are embodied in the rigid panel design) through the building envelope have resulted in a high commodity investment. Further, imported materials, systems and designs have resulted in a large investment of time, money and resources, which are not affected by heat conduction.

6.3.6 MATERIALS WILL NOT DETERIORATE IF ONE OF THE CONDITIONS FOR DETERIORATION IS ABSENT

The main materials used in the construction of the Coldstream house are wood, metal and foam insulation. Wood will deteriorate under specific conditions including optimal temperature, optimal moisture content, and the presence of spores and oxygen. Because the structure is on the outside of the thermal envelope, the optimal temperature is not often attained to allow any spores to survive. Furthermore, properly kiln-dried lumber should not contain enough moisture to sustain any growth. Metal and foam insulation are both relatively inert materials. Conditions that normally occur in a residential home (generation of moisture, furnace heat) will not likely affect these materials. However, intense heat, like that generated from a fire, would have an effect on both of the materials. In the instance of a house fire however, the thermal panels, the wood structure and any other materials in the building would be in jeopardy.

Stability - If just one of the conditions for deterioration of wood is absent, the material will remain intact and continue to remain stable as part of the building. If however, all of the conditions for deterioration are present, then the material could be compromised. Eventually, deterioration of the material would lead to the deterioration of the structure, and a degradation of the stability of the building.

Durability - If the conditions existed to promote the deterioration of any of the primary building materials in the Coldstream house, then the durability of the building would be immediately affected. If any material degradation occurred (wood deterioration, or destruction of the thermal panels) before the end of a fifty year use-life the intended use-life of the building would not have been attained, and the durability of the building would have been sacrificed.

Commodity - The commodity investment in the Coldstream house was reliant on a use-life of 40-50 years. If any of the primary building materials were to deteriorate and the durability is jeopardized, then this investment in the building will naturally have been affected and threatened.

6.3.7 MATERIALS MUST HAVE SUFFICIENT TIME TO CURE UNDER OPTIMAL CONDITIONS

- Wood: In order for wood to remain dimensionally stable when used in the construction of a building, it must be kiln dried to achieve a moisture content of 19%. If the moisture content is any higher (known as green wood), then dimensional changes could occur as it looses moisture.
- Polyeurethane foam: This foam insulation is produced and allowed to set under strict conditions. If these conditions are not in place, the material might not attain its intended thermal value or prematurely deteriorate.
- Sheet metal: Sheet metal production similarly occurs under strict conditions.

Stability - If the wood was not cured properly, and had a moisture content higher than 19%, then the stability of the structure could be in jeopardy as the material would be prone to bowing, cracking and moving within the structure. Although this might not be immediately detrimental to the structure, long-term movement would likely result in the premature failure of the structure.

Durability - The use of green wood in the construction of a building would undoubtedly affect the potential durability of a building. Long-term stresses on the structure from warped materials could cause the structure to prematurely deteriorate before the end of its use-life. If the insulation and metal as part of the thermal panels were to not function as intended, then the durability of the building would be in jeopardy. The thermal panels are central to survival in the arctic climate. Without them, the building would not be able to protect the occupants and be used for its full use-life.

Commodity - The premature deterioration of any of the materials due to incorrect manufacture and curing processes would jeopardize the large commodity invested in the building, as the intended use-life would be sacrificed and the building would not be used to its full anticipated potential.

6.3.8 MOISTURE CAN CHANGE THE PROPERTIES OF MATERIALS

Of the primary building materials in the Coldstream House, wood is perhaps the most likely to be affected by the presence of moisture. While not only resulting in dimensional changes in the lumber, moisture (in its liquid form) could also promote wood rot if other conditions were present. Moisture (in any form) is not likely to affect the foam insulation, or the metal panels that have been treated with a finishing coating.

Stability - If moisture were to penetrate the timber frame of the building then it is likely that dimensional change would occur. Although a wood frame structure is versatile enough to accommodate a significant amount of structural movement, swelling of the structural members could eventually compromise the structure and stability of the building.

Durability - If the wood structure is affected by moisture, then the original intended use-life of the building could be severely compromised. Premature degradation of the structure would affect the whole building's ability to continue to function for the duration of its life.

Commodity - A significant amount of commodity investment is embodied in the thermal panel system of this building. If, however, the structure is compromised, then the thermal panels themselves cannot be held in place, and the building would collapse. Any investment in the thermal panels would be jeopardized and lost.

6.3.9 MATERIALS CAN CHANGE DIMENSION WITH TEMPERATURE CHANGE

The cold Arctic climate is full of extremes, with regular changes in temperature. The materials that comprise the thermal panels in the Coldstream house however, are relatively inert and will exhibit negligible changes due to these fluctuations. On the other hand, a wood structure, if it was not properly dried (ie. less than 19% moisture content) can be greatly affected by temperature change. The moisture housed in the material will swell or contract, thereby possibly affecting the dimension of the material.

Stability - In all likelihood, the wood that was used for the structure of the building had achieved the industry standards of 19% moisture content and would have been affected very little by any temperature change. However, in the event that "green" wood had been used, any significant temperature change would have affected the dimension of the material, causing warping and cracking, and thereby affecting the integrity of the structure.

Durability - The sheet metal sheathing and rigid insulation are both materials that are incorporated in this building for their stable qualities. Their minimal dimensional variation during changes in temperature makes these materials central to the durability of the building. Any seasonal or daily temperature changes, within and without the building will not affect the building's ability to function for its intended use-life. If the wood structure is compromised, and there are cyclical dimensional changes in the material, then this would naturally affect the overall ability of the building to function for its intended duration.

Commodity - The large commodity investment in the building materials for the Coldstream house is clearly illustrated in the design choice of the construction materials. The relatively inert reaction of each material to temperature changes makes the building stable and durable and therefore an excellent investment in the building's longevity.

6.3.10 THE WEAKEST MATERIAL WILL FAIL FIRST

Of the three building materials in the Coldstream house (wood, foam insulation and sheet metal) the most vulnerable, and therefore the weakest, material is the wood. Because it is more susceptible to deterioration it is more likely to fail before the other relatively inert building materials.

Stability - Since the wood comprises the house's structure, its failure will directly impact the stability of the building.

Durability - Central to the Coldstream house extending through its use-life is maintenance of the building's structure. Without it, the essential thermal materials cannot be in place to play their role. Therefore, the failure of the weakest material in the system will naturally lessen the durability of the building.

Commodity - As with the building's durability, the commodity investment in the building centers on the maintenance of a structure that creates the form of the building. Without this frame, the other materials cannot provide any protection for the occupants, and the commodity invested in their design, manufacture and transport will be lost.

6.3.11 NO MATERIAL IS INFINITELY STRONG

The strength of the wood used in the frame of the building lies in its fibrous structure. In order to maintain this strength, it must remain relatively dry in order to avoid any deterioration (ie. wood rot). Although the strength of the sheet metal is not central to the success of this building, the maintenance of its shape and integrity is important. Therefore, intense heat, such as that from a fire, would affect this material.

Stability - If the wood structure of the building were to deteriorate the strength of the material would eventually be lost and the stability of the building as a whole would be threatened. Maintaining the integrity of the sheet metal however, is not essential to the stability of the structure as a whole.

Durability - As previously discussed, the deterioration of the wood would naturally affect the structure of the building, and therefore the durability of the building. It cannot continue to provide protection to the occupants if the structure no longer exists. If the strength of the sheet metal were to be compromised, then eventually the envelope of the building would deteriorate and no longer be able to protect its occupants. The building would no longer be considered durable.

Commodity - Return on the commodity investment in this house centers upon each of the materials functioning to its full potential. If the strength or integrity of any of the materials were to be threatened, then the commodity investment in the building would be affected in a negative manner.

CHAPTER 7: DISCUSSION

The analyses presented in the preceding chapter have provided a holistic view of the properties of each of the three buildings. The physical remains of the case study buildings were examined according to the eleven principles. This information was then used to evaluate how each building meets its functional requirements. While the analysis illuminated the strengths and weaknesses of each building, it also proved to identify several overriding patterns and points of interest that further our comprehension of the discipline of building science and our understanding of buildings in general.

It is important to note that the aim of this investigation was not to determine which of the case studies is overall a better building. Although a comparison of this sort could be done for a specific topic, such as thermal performance, this is not intended to be a competition of technology versus traditional knowledge. Rather this study is an extensive examination of each building in an attempt to illustrate that a holistic analysis of *any* building is possible, and to show the versatile and wide ranging information that can be gleaned from such an analysis.

7.1 MATERIALS AND COMPONENTS MUST BE ANALYZED WITHIN THEIR SPECIFIC CONTEXT

All buildings are, at the base level, comprised of materials. It is essential to analyze these materials within the context of their intended use, as they often play different roles in different buildings. For example, the whalebone house used snow as an insulative material, helping to slow the migration of heat, thereby insulating the interior space. Snow in the snowhouse, while used for its thermal properties, was also the primary structural component. The blocks of snow actually comprised the structure of the building while also providing thermal protection. Therefore, when answering a question such as "How will heat flow affect the stability of a building?", it is imperative to look at *how* a material is used in the building, its role in the building envelope and in the overall building itself. Heat as it melts the snow will undoubtedly affect the structure of a snowhouse, but will not likely affect the structure of a whalebone house. Interestingly, snow in the case of the Coldstream house is considered the nemesis of the building. The envelope strains under the ravages of the snow, and labors to exclude the material that the other two buildings have embraced and incorporated into the envelope itself.

A similar example can be found in the role of the hide in both the whalebone house and the snowhouse. The former uses the hide as an essential component in forming the composition of the walls and roof, as the sod and snow are placed on the hide, which acts to carry and transfer the load to the whalebones. In the snowhouse, the hide is not an essential material, and when it is used, it creates a protective thermal air space to increase occupant comfort and longevity of the building. The same material is used to accomplish two different tasks. As a result, the analysis of every building must be performed individually and in the context of the region and the technology employed. Even analyses of the same building must acknowledge that materials can play different roles in different contexts and in light of various research questions. Materials are often versatile, and their use is what makes each building unique.

7.2 INTERRELATIONSHIP OF PRINCIPLES

In analyzing the buildings according to each principle, there is a distinct overlap of the fundamentals of some principles and what they represent. For example, principles #3 (heat travels form the hot to the cold), #4 (the greater the difference in temperature, the greater the heat transfer) and #5 (heat conduction will always occur) all discuss the movement of heat through the building envelope. Likewise, principle #1 (forces exist to achieve a balance) includes heat transfer, but in the more general context of the forces that act on a building. Principle #2 (there is always a point of diminishing return) is related to principle #11 (no material is infinitely strong) in that both principles will likely inform design decisions in the face of investment returns.

It appears that the principles become more interrelated when a building that is composed of fewer materials is analyzed. In these instances, the lesser number of materials must individually perform more functions and it becomes imperative to understand how each material is maximized and what mechanisms will jeopardize its function. For example, the snowhouse has the least number of materials of the case study buildings. Heat appears to be snow's biggest nemesis, and the analysis of the effects of heat on snow recurs in the discussion of most of the principles. The Coldstream house and the Whalebone house, on the other hand, with more materials performing specialized individual tasks, less of the principles are interrelated and address the same aspects of the building.

Although the principles can be highly integrated, it is essential to continue to use and understand them individually. As stated in Chapter 3, there are undoubtedly many other principles pertaining to materials, components and systems of a building, but those listed here have been scrutinized and distilled to be immediately pertinent to building science. Their highly interrelated nature only serves to illustrate that the various areas of the building are similarly interrelated, and that no aspect of a building can be studied in isolation. It is still imperative however, that each principle continue to stand alone as their interrelationship will be different for each building. If any of the principles were to be amalgamated, the detailed understanding of the building would be lost to generalizations, and a complete awareness of the building would be compromised for brevity and apparent, yet falsely so, efficiency.

7.3 INTERRELATIONSHIP OF A BUILDING'S FUNCTIONAL REQUIREMENTS

The functional requirements of a building are those prerequisites necessary to function as a building. Namely a building must be stable, durable and have an embodied commodity that has been invested in the building. Although each is a separate functional requirement, they are highly interrelated. Primarily, there is an inextricable relationship between durability and embodied commodity. Durability is based strongly upon the intended use life of the building. If it is expected that the building will in fact have a long use life, like the Coldstream house, then the builders/owners would want it to be highly durable. In order for the building to be durable, there must be a larger initial commodity investment in the building to ensure high quality materials and workmanship. Alternatively, if a building is expected to have a very short use life, like the Inuit snowhouse, then it is likely that there will be a low embodied commodity investment in the building. This direct relationship between embodied commodity and durability (low durability equals low embodied commodity) appears to have been an innate aspect of pre "fiscally oriented" construction. This is perhaps the result of the owner/investor being the same as the builder and the occupant. In many modern contexts however, investors in construction want to have a durable building, with a long use life, but are not willing to invest the appropriate commodity to ensure the corresponding durability. As a result, the building often suffers premature aging and in many cases, the third functional requirement, stability is jeopardized. It becomes apparent that the interrelationship between the three functional requirements is perhaps the most important consideration in evaluating a building.

7.4 INTERRELATIONSHIP OF PRINCIPLES AND FUNCTIONAL REQUIREMENTS

While it appears that the principles of building science are interconnected, and the functional requirements of a building are similarly interrelated, the analysis has also revealed a relationship between the principles and the functional requirements. For example, the principle "there is always a point of diminishing return" (principle #2) is directly linked to the building's embodied commodity, one of the functional requirements. The designers of the buildings must delicately balance the commodity invested in the building against the return from use. Understanding materials and their limitations is central to balancing commodity investment. Similarly, the principle "the weakest materials will fail first" (principle #10) is closely linked to the functional requirement of durability. Understanding the nature of materials and components, and how they are assembled and react to one another, is essential to maximizing the durability of a building. Durability cannot be predicted without consideration for materials and components.

7.5 BUILDING COMPOSITION

While most buildings are comprised of a myriad of materials, at its most basic level, every building must be composed of at least one material that serves to adequately separate an interior environment from the exterior environment. In the case of the Inuit snowhouse, snow serves to efficiently and successfully create and maintain a building envelope in the harsh northern climate. By comparison, the whalebone house used four main materials (snow, sod, hide, bone and sinew) and the Coldstream house utilized a myriad of complex highly fabricated materials. When a building utilizes fewer materials, each material must naturally perform more functions within the enclosure. In the instance of the snowhouse, the snow gives structure to the building, and provides insulation and protection. In the whalebone house, snow provides mainly insulation and protection, while the bone and sinew provide the structure to the building. In the Coldstream house, snow is not used; in fact, the building is designed to keep snow out, and not integrate it into the design.

In looking at the case study buildings, several interesting comments can be made based upon their composite material make-up. The analysis revealed that in the case of the snowhouse, that utilizes only one main material, the stability and durability of the building were easily and expediently compromised by one of a few factors. Namely, heat was the main factor that could single-handedly affect the stability of the building and its durability in the face of degrading forces. Interestingly, heat is the natural by-product of use, and therefore, if the building is to be used by any occupants, it will naturally deteriorate. This quality is clearly reflected in the embodied commodity that the builders invested in the building. Snowhouses can be built in as little as two hours, and rarely did builders take more than a few days to construct a very large dwelling.

The Coldstream house, on the other hand, with more complex and different materials, has many different forces that will effect the specialized areas of the building enclosure. The building therefore appears to be more durable as there is no one force that will compromise the entire building at once. The highly specialized nature of this building is clearly reflected in the large commodity that must be invested in the building from its inception through construction to occupation.

The analysis has revealed that there are both positive and negative aspects to using more than one material in the construction of a building. While a building composed of one main material may allow for easy and expedient design and assembly, if that one material fails, then the entire building is in jeopardy. Therefore, the commodity input for making a building with more materials is often worthwhile, as it is more versatile in a myriad of unpredictable conditions.

7.6 BUILDING SCIENCE AS AN INTERDISCIPLINARY TOOL FOR BUILDING ANALYSIS

Building science is comprised of three component parts: the physical elements of a building, the principles of the materials and components and the functional requirements of every building. The analysis of the three case study buildings has revealed that there is an interrelationship within each section (ie. many of the principles are interrelated) and between the sections (the principles and the functional requirements are interrelated). These relationships reveal an inherent bond within the discipline of building science. The corollary of this interrelationship is a similarly strong correlation between the component parts of the building. As a result, it is imperative to study, understand and analyze a building in a holistic way, as the component parts are inherently interrelated.

The analysis of the preceding chapter has provided a wealth of information about each building from various viewpoints. Information from this analysis can be sorted, interpreted, studied and used based upon one of the following perspectives:

1. by building
2. by principle
3. by functional requirement

(See figure 7.1 on page 150)

Therefore, any discipline could glean any amount of information from this analysis. If, for example, a discipline was studying buildings from a particular climate, then the information could be sorted by building, as this would present information from a cross section of buildings from one particular climate. Or, if a discipline were to focus more on understanding the affects of climate and occupant use on the durability of a building, the information could be sorted by functional requirement. A myriad of both academic and industry related disciplines could glean information from a variety of perspectives, about many different topics. Although the possibilities are as endless as the potential number of research questions, it is immediately obvious that the initial research objective of this thesis has been met:

To illustrate how building science is integral to interdisciplinary examinations of buildings through time

Buildings are a wealth of knowledge that can be tapped in order to more fully understand our built environment, from the past and the present, and perhaps guide us to create a better future.

7.7 LIMITATIONS OF THE ANALYSIS

Any building science analysis will benefit from a complete set of information pertaining to the building to be studied. As such, analyzing buildings from an archaeological context, such as the whalebone house, introduces an element of the unknown, as there are always specific details that are unknown, undiscovered or unfamiliar to the investigators. Similarly, it is often difficult to analyze different forms of vernacular architecture, as the design and construction is customarily an inexact science, where factors such as material and labor availability will determine the eventual construction of a building. By extension, vernacular buildings are often "works in progress" where there are no exact specifications for materials or construction plans. In fact, all buildings will continue to grow and change over time. As Stewart Brand has eloquently described in his book How Buildings Learn, a building will inevitably evolve with changes in occupants and use. As such, a building science analysis will investigate what is present at the time, and will therefore capture one moment in the evolution of a building.

While this form of analysis is perfectly suited to modern construction, where there is a clearly defined building project, we must be aware of its limitations in investigating more fluid forms of building. For example, it is difficult to assess the exact impact of the snow in both the snowhouse and the whalebone house as snow availability is often varied, and drifting snow will often add to the original building. Therefore, two scenarios of the same building could see vastly different amounts of an essential building material. It is important therefore that a building science analysis remain versatile to each situation. In these latter instances, more generalized comments would be appropriate, while a modern building analysis may be more accurate with its conclusions. As such, the level of detail in the analysis of each building is varied. In fact, the level of details within the analysis of the same building may be varied, depending on the information available.

7.8 SUMMARY

The analysis of the three case study buildings was an important exercise to understand the inherent nature of both building science and buildings themselves. In so doing, the true nature of the discipline has been revealed. This investigation has forced us to perceive of the built environment in a different way from a changed perspective. The analysis illustrated that we must look at materials and components in their specific circumstances and contexts. Furthermore, it is essential to perceive of a building as a system, to examine, study and analyze a building as a whole, as its component parts are high integrated. Finally, this method of analysis is essential in understanding buildings from different perspectives, to open our eyes to understanding that other disciplines will use the information from the building and will use it successfully.

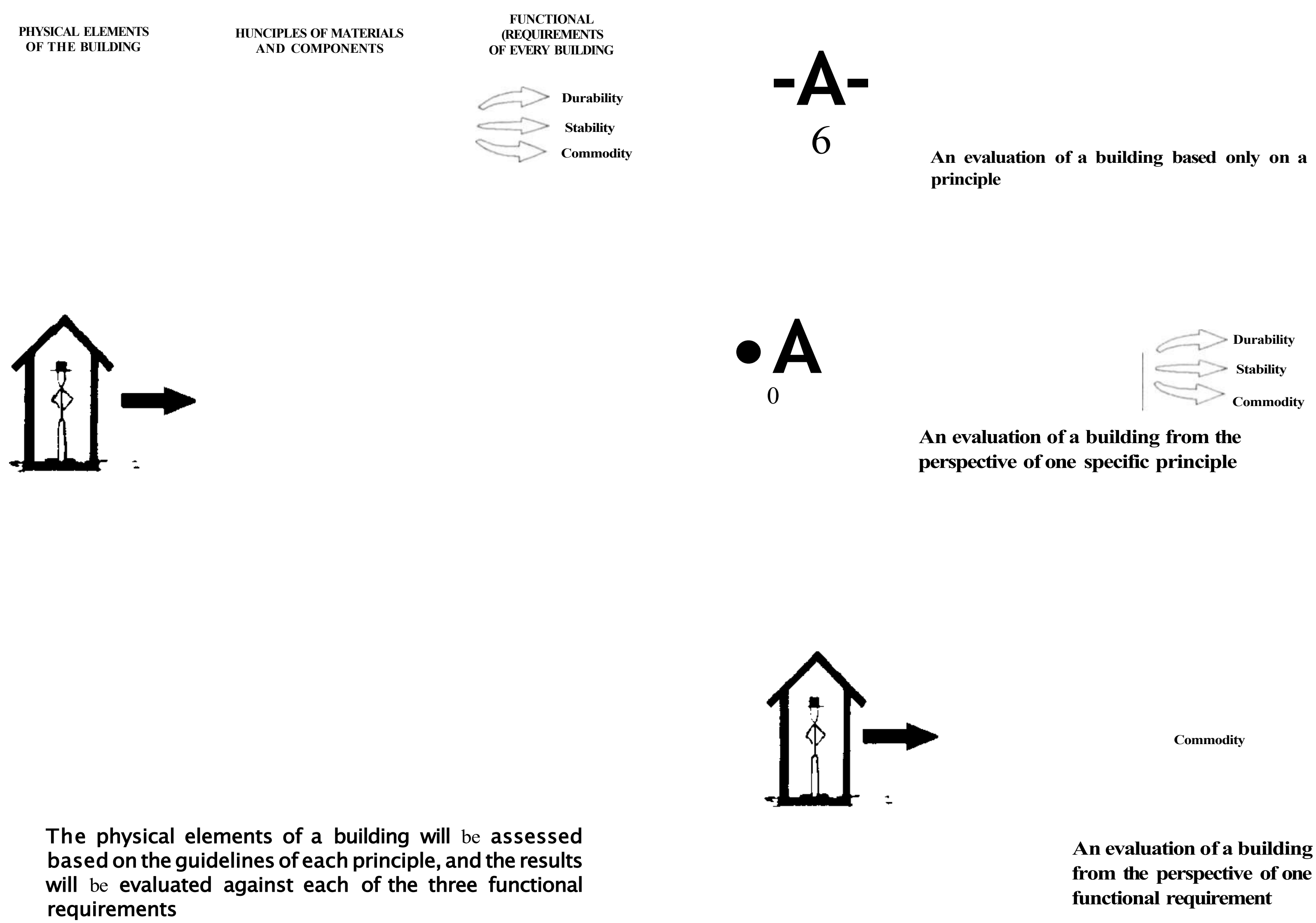


Fig 7.1 Schematic for a building science analysis and the possible perspectives for the application of the analysis

CHAPTER. 8: CONCLUSION

The field of building science is a versatile instrument for architectural analysis. The discipline can be used to analyze buildings within many disciplines and from a variety of research orientations. The result is an interdisciplinary toolkit that can be widely used to compliment and illuminate innumerable research designs. Understanding *why* we build and *what* we build is central to an initial comprehension of this building science toolkit. Furthermore, investigating the need for a holistic approach to building investigation has been an overriding theme of this thesis. Understanding the discipline of building science itself however, is central to the investigation. In *every* building there are the physical elements and functional requirements, all of which are bound by the principles of materials, components and systems of a building. This is the nature of the discipline, and the essence of understanding buildings.

The analysis of the Snowhouse, the Whalebone house and the Coldstream house have each been invaluable in understanding how a building science analysis can foster an understanding of buildings from vastly different time periods. This process can be extended, in future research, to buildings from divergent geographical locations and culture areas. Furthermore, understanding more complex issues such as lighting, acoustics and air quality will increase our understanding of the built environment. Finally, cultural influences on buildings and design decisions will help to create a more individualized profile of any building.

This thesis has, in particular, illustrated a comprehension of the performance requirements of buildings. In a society where many buildings often symbolize societal and monetary status, and visual appearance often takes precedence, it is important to remember that ultimately, each building must remain *stable* and be *durable* given the *commodity* invested in the building. The analysis has illustrated the interrelationship of these variables and how building science can assist us in understanding them further. For example, it has been argued that stability embodies issues of occupant safety and building durability. Durability and use-life of a building are inextricably tied to the commodity invested in the building. Understanding each of these performance requirements and their interrelationship is the basic groundwork for understanding *any* building. Whether commodity investment, for example, is from the perspective of a multi-million dollar investment in the modern marketplace, or in the context of studying an extinct material culture, understanding how the physical elements themselves meet, or don't meet, each of the performance requirements is invaluable to understanding the basic building itself.

What has been presented in this thesis is an analysis of a building at its most fundamental level, where all buildings are comprised of the basic physical elements and the most basic performance requirements. Very few buildings however, are comprised of only these characteristics. Buildings are built for people, and both people and cultures have varying requirements of their buildings based upon geographical and cultural requisites; buildings are the products of culture, and therefore are naturally imbued with cultural identity. In order for an understanding of buildings to continue beyond the scope of this investigation, and become more individualistic in nature, there is a need to focus on analyzing and understanding buildings within their cultural context. This would include understanding buildings within their "spheres of cultural influence." In broadening the context of the analysis, so will we be able to gain additional insight into both the building and the builders, but also gain a more thorough understanding of buildings in general.

Buildings are a complex interrelationship between technology, culture and individuals. While they reflect both architectural and engineering feats and fashions, they similarly symbolize the cultures that built and used them. The holistic perspective facilitated by the use of building science is a rich analytical tool, and of profound introspective value. It is through the use of building science that we can begin to understand our buildings, our society and ourselves.

APPENDIX A: INDEX

This is a list of definitions for the various spheres of cultural influence that will affect how a building is designed, built and used. The terms have been intentionally defined in order to eliminate any ambiguity concerning how each will influence the built form.

ECONOMY
practical and theoretical science of the production and distribution of resources and wealth

EDUCATION
the systematic instruction, schooling or training given to a person or group

ETHICS
set of principles relating to cultural and/or individual morals; rules of conduct

HEALTH
condition of the body and mind of an individual or society

HISTORY
the past important public events of a society or culture; could influence cultural tradition

POLITICS
the organization of civil administration and public affairs

RELIGION
particular system of faith and worship of the individual or society

SEX
female or male

TECHNOLOGY
science of practical or industrial arts

The definitions for these terms have been inspired by definitions from various sources:
Brett 1997; Curl 1992; Smit and Chandler 1991; Sykes 1984.

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