MASTER BUILDER OF THE MIDDLE AGES AND DESIGN BUILD OF TODAY: AN ANALYSIS AND COMPARISON

By

VINCENZO EMPRIN-GILARDINI

Laurea, Civil Engineering, Politecnico di Torino,
Torino (Italy),1999

Submitted to the Department of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degree of

MASTER OF ENGINEERING IN CIVIL AND ENVIRONMENTAL ENGINEERING

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2000

Signature of the Author
Department of Civil and Environmental Engineering
May 2000

Certified by
Charles H. Helliwell
Senior Lecturer, Civil and Environmental Engineering
- Thesis Supervisor

Certified by
Jerome J. Connor
Professor, Civil and Environmental Engineering
Thesis Supervisor

Accepted by
Professor Daniele Veneziano
Chairman, Departmental Committee on Graduate Studies

MASTER BUILDER OF THE MIDDLE AGES AND DESIGN BUILD OF TODAY: AN ANALYSIS AND COMPARISON

By

Vincenzo Emprin-Gilardini

Submitted to the Department of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degree of Master of Engineering in Civil and Environmental Engineering

ABSTRACT

Design and build is both an old and a new method of project delivery. It is rooted in antiquity, when the master builder was usually both the designer and the constructor of the projects he envisioned. Labor force was used to haul large blocks of stone that skilled craftsmen would later fashion into useful components of a structure. Throughout this process, their efforts were controlled by the individual responsible for the project's design. The plans were often little more than an image in the designer's mind, and were realized only in the course of the actual construction. It was essential, therefore, that the designer be the builder as well.

During the Renaissance, building design became so complex that the master builder could no longer be responsible for both the design and the construction of a project. The traditional method of project delivery grew out of this need for more extensive resources, until the design and build method once practiced by the master builder regained popularity in the 1970s. The reason of this phenomenon lays in the need of clients to investigate ways of controlling project costs and reducing delivering time. Today the term *design and build* refers to a method of project delivery in which a single entity provides to the client all of the services necessary to both design and construct all or a portion of the project.

An analysis of the role of the master builder in the Middle Ages is provided. The reason why the Middle Ages were chosen lays in the fact that during this period outstanding projects were completed in Europe and the role of the master builder as a designer and constructor was then best represented. The construction of the cathedral of Chartres in France is used as an example. The modern concept of design and build is analyzed as well, providing the Øresund Tunnel project between Sweden and Denmark as an example. Finally, master builder and design and build are compared, with a focus on the similarities, the differences, what can be learned from the past and how it can be applied.

Thesis Supervisor: Mr. Charles H. Helliwell
Title: Senior Lecturer, Civil and Environmental Engineering

Thesis Supervisor: Professor Jerome J. Connor
Title: Professor, Civil and Environmental Engineering

ACKNOWLEDGEMENTS

I would like to thank my thesis advisor, Charles H. Helliwell, for his support and advice. Particularly, for his great idea of connecting the design and build method of today to the work of the master builders in the Middle Ages. He helped me with great enthusiasm to focus on the topic and to organize my work.

TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

From an historical perspective, engineering and construction have been integrated longer than they have been segregated. The pyramids, the cathedrals of Europe, and other monumental accomplishments all used integrated teams, or master builders. Segregation did not occur until after the Renaissance. The process worked well in some cases, but not so well in others, for example, when complex projects called for adjustments during construction that were frequent and costly[1]. According to Michael J. Taylor, today the trend is swinging back to the master builder concept, especially for fast-track projects that require integrating many disciplines.

This work is essentially divided into three sections. The first section, namely chapter two, deals with the figure of the master builder of the Middle Ages, his role, his characteristics and the environment within which he was immersed. The second section, namely chapter three, describes the modern concept of design and build as an effective alternative for project delivery. The last section, namely chapter four, represents a critique and a comparison between the figure of the old master builder and the design and build method of today. Some of the questions that this chapter tries to answer are: what are the similarities and differences of a project carried out in the Middle Ages and a project carried out in the 21st century? To what extent nowadays' environment is different from the one the master builders used to work in? Are the goals and objectives still the same ones? What are the lessons learned from the experience of the old master builders and how could they be applied?

Throughout an analysis of the conclusions taken from the previous chapters, a new way of approaching a design and build project is suggested.

1.1 References

[1] Taylor, Michael J., 2000, "Return of the master builder" *Civil Engineering*, ASCE 70(3), 41-43

2. THE MASTER BUILDER

2.1 Historical background

European architecture went through a period of great development and building activity between about 1150 and 1450. Such activity had not been experienced since the fall of the Roman Empire. The economic improvements, resulting from the development of trade and commerce, generated the rise of volume and quality of the building activity. Masonry was becoming highly organized throughout Europe and the Gothic style, characterizing the Age of the Great Cathedrals, was born[1]. About the year 1200 over a dozen cathedrals like Chartres, which is analyzed in detail at the end of the chapter, were being built in the region around Paris, together with some four hundred churches, thousands of abbeys, bridges, town walls and houses. It was one of the greatest ages of building the world has ever seen. Some time during the 1230s, when Chartres was almost complete, the fever died away. Work slowed down, and buildings that had been completed in a few decades, now took centuries[2].

Among all the works of this Age, the analysis of the master builder will be related to the monastic architecture for many reasons. Firstly, cathedrals represent very large and complex undertakings, involving issues of planning as well as design: to have an idea about what a great cathedral meant during the Middle Ages, it is sufficient to think that they represented the largest architectural units in existence at that time. Secondly, cathedrals are both a work of art and a work of construction together, where issues strictly related to construction, such as field organization, labor force, direction of the works, methods of contracting are also connected to art, in particular sculpture. Finally, they represent a way of life, that is a personal commitment to which many of the most brilliant men and women of the Middle Ages have dedicated themselves. These reasons are more than ample to justify the preference given to these kinds of buildings rather than to an office building, for example. No building, however, can be understood just as a "work of architecture": it is necessary to know why it was built and how it was used[3].

2.2 Funding the medieval constructions

The usual method for funding the construction of a cathedral in the Middle Ages was to create a fund that was provided by saving a certain amount of the regular revenues of the church. The fund was supplemented in various ways. Bishops, canons, and occasionally citizens taxed themselves on a voluntary basis; legacies also provided contributions. Numerous documents witness that from the XIII Century onwards episcopal and papal indulgences were granted for the construction of almost every great cathedral[4].

Many documents related to the financing of Milan Cathedral have survived. In an entry of the Register of the Building Works dated September 17, 1387, it is stated that free services were rendered by advocates and notaries, even by the mayor. Gian Galeazzo Visconti, Duke of Milan, together with his family, launched a campaign for funds for the building by collecting gifts of jewels, gold and even food. The community itself was mobilized: groups of girls dressed in white and accompanied by trumpets and pipes toured the city begging for alms. A donation from the prostitutes of Milan is also noted[4].

Particularly celebrated relics also represented a big source of funds. Following the fire that damaged the cathedral of Laon in France in 1112, a group of canons took their most sacred relics, saved from the fire, and traveled from town to town, both in France and in England to raise money for the reconstruction. Everywhere the relics excited enthusiasm and the canons managed to return to Laon with sufficient contributions for the repairs[4].

The enormous veneration that was accorded to the "Chemise of the Virgin" preserved at Chartres (France), contributed to a great extent to the raising of funds that made it possible for the cathedral to be built within the short space of 27 years. "The theory that the Gothic cathedrals necessarily took hundreds of years to complete, is untrue. When building funds were available, progress could be very rapid"[4].

From the XIII century the practice of indulgences provided a means for financing the construction or reconstruction of cathedrals. In 1272, the Bishop of Regensburg managed to persuade twenty-two of his fellow bishops to proclaim indulgences in their dioceses for those who gave money for the building of Regensburg Cathedral[5].

However, according to research carried out by John James, the Middle Ages did not have the same sophisticated funding and cash flow techniques that can be found in later centuries to complete the projects. The amount of the money collected or donated varied from year to year, and the works had to stop when the money ran out. The masons had to leave when there was no money left, to eventually return when the Chapter of the church could afford the works again. This is also one of the reasons why different crews worked on the same project at different times.

In any case, all concerns about financing, constructing, maintaining the cathedrals' fabric, ensuring the collection of revenues to be added to the fabric fund, entering into contracts, arranging the payments for material and labor and appointing a master-builder in charge of the technical side of the building operations, were handled by the chapter. One specific member, called *custos fabricae* (keeper of the fabric), was in charge of admnistrating the business[4].

2.3 Supply of material and labor

According to W.Swaan, adequate supplies of material and labor represented a big challenge in the construction of cathedrals. Most importantly, adequate supply of stone was necessary, as this was the main material used in the construction. Because the transport cost was three or four times larger than the quarrying cost, the location of the quarry was of great importance. Actually, it was not necessarily a question of how far was the quarry from the construction site, as water carriage was far easier and cheaper than land transports. In fact, land transport was made possible by the use of ox or, eventually, by horse-drawn carts and wagons, which was a slow and expensive means of transportation. This is the reason why sometimes stone could be obtained from abroad at competitive prices.

Moreover, since the construction of a cathedral was a very big project, the needed resources could be sought beyond local boundaries. This is the reason why the French mason William could be brought from Sens to Canterbury, and why French and German masters could be called to Milan for advise regarding the new cathedral[6].

Extensive use was also made of timber, both for the frameworks, and for the construction of the roofs. These roofs were often constructed before completion of the severies and right after the skeleton of the vaulting ribs was completed, in order to assure protection and permit the earliest consecration of the church.

The high costs in transportation encouraged the working or at least the rough finishing of the stones at the quarries. The success of this method lead, by the end of the Middle Ages, to the establishment of carving schools right besides the quarries, in order to be able to carve sculptured figures and interior furnishing right were the material was supplied.

2.4 The organization of a cathedral construction

The organization of a traditional ecclesiastical building work of the Middle Ages can be summarized as follows[1]. On the one hand there were the employers, or the client, which was the abbot or prior and his convent, who assigned the general supervision of operations to their appointed agents, the master of the works and the controller. On the other hand there was the master builder and his assistants of various grades who were engaged and paid to carry out the work.

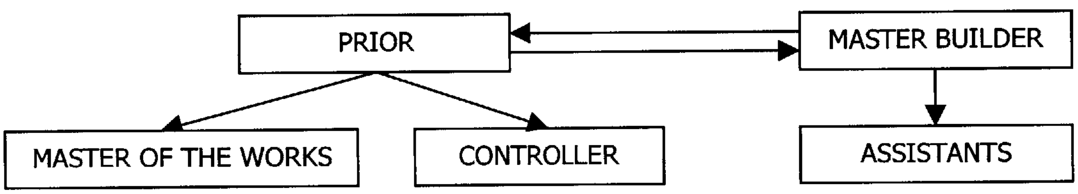

Figure 2.1 - Building organization

2.5 The labor force

According to W.Swaan, the most important craftsman in the construction of the Gothic cathedrals was the stone mason and his associated workers. Documents report that, for the construction of the main portal only of the Rouen Cathedral, fifteen master masons worked for fifteen years carving the thirty-four large statues, the numerous small figures and the tympanum. The medieval craftsmen represented a very wealthy class, as documented by their tax rating as well as by the properties left in their wills, at a time when only a very small proportion of the population even made a will. In addition to a very good salary, building workers used to receive various other incentives for their dedication and results.

As far as the typical working day goes, an average of 12-hour-work per day was the rule for summertime, while during winter a 9-hour working day was the average. However, work stopped at noon on Saturdays and there were numerous holidays throughout the year, generally thirty to forty weekday holidays. In general, medieval construction workers did not fare badly if compared, for instance, to their counterpart in the nineteenth Century's industrial society.

The typical medieval stone mason worked basically for two clients: the Church and the ruler, which could be represented either by the king or the feudal lord. In fact, the stone mason's typical jobs were the construction of cathedrals and castles or fortifications. All the other medieval constructions, such as buildings or dwellings, were of light construction, mostly made of timber.

It was only around the end of the Gothic period that the municipal corporation started playing an important role. Because of the fact that his work was specialized and required only for certain constructions, the stone mason was often obliged to travel extensively in search of a work. In fact, as soon as one piece of work was finished and another begun, the masons moved from place to place, though some of them remained for a lifetime on the construction of one single building[1]. The extreme mobility of the medieval mason turned out to be the main reason for the establishment of the institution of honorary freemasonry. Being always away from home, it was natural for the mason to turn to the mason's lodge, which, from being just a shelter for him and his tools, became a place of discussion in the style of a club. Secret signs and passwords were used to distinguish fellow masons[4].

2.6 The master builder

The master builder was generally a stone mason with knowledge of the craft, that had extended his knowledge into subjects such as geometry and planning. His role in the construction was to direct his own masons as well as the master-carpenter, the master-smith and so on. In very large projects, such as cathedrals, his task was also to estimate the labor and the quantities of materials needed, and eventually, to administrate the finance, thus becoming the contractor. His salary was really high when compared to the one of a fully qualified stone mason; moreover, differently from the stone masons, who were hired by the week, he was often engaged for the year, or even for life. Employing a master builder for life made it possible to provide architectural continuity to the work, while at the same time setting the scene for the evolution of the professional architect of today[6]. In some cases, the master had a high contractual power, as it is the case of the master of Lugo Cathedral in Spain. The master, a certain *Maestro Raymundo*, apparently lacking confidence in the local currency, managed to obtain a clause in his contract stating that he would be paid in kind if that currency fell in value.

The master was also what nowadays is called an architect, meaning "the person responsible for the design of the building and its supervision to ensure that the work is carried out according to that design" [4].

The terms of the contract that was stipulated to hire the master builder were clear and definite. Frequently, he contracted not to leave the neighborhood of the building, or, if sick, he forfeited his pay even though it happened through accident while at work. However, the master builder was paid on the holidays when no work was done. Moreover, in addition to his pay, he was given some meals, a couple of gowns of fur, and sometimes a house for his family, with keep for his horse[7].

There were basically two types of master builders: those who were competent in construction, repair and maintenance, and those who took part in the conception and the development of the Gothic architecture; the constructor and the designer. In any case, either one never entirely abandoned the chisel.

Not only did the master have a certain power within his crew, but he also could express and please himself with his decisions, often irrespective of what the client may have thought or of any plan the previous master may have started to implement[6].

Unfortunately, the master builders have never been really recognized: their work was generally only distinguished by the name of the abbot or bishop under whose aegis they worked. However, some masters signed their work with their name[7].

2.6.1 Examples of master builders: Villard de Honnecourt and Henry Yevele

Villard de Honnecourt was a master builder who lived in the XIII Century, probably the most creative period of the entire Middle Ages. This master was chosen here because one of his sketchbooks survived the centuries and is still preserved in the Bibiothèque Nationale in Paris. The sketchbook represents a great example of the cathedral-designer's working methods and interests. The preface of the book reports: "Wilars de Honecourt salutes you and implores all who labor at the different kinds of work contained in this book to pray for his soul and hold him in remembrance. For in this book may be found good help to the knowledge of the great art of masonry, and of devices in carpentry. It also shows the art of drawing, the outlines being regulated and taught in accordance with geometry". There are plans, sections and elevation of buildings, details of carpentry construction as well as designs for church furnishings and design of construction machines[4]. Unfortunately, exhaustive design of the works whose implementation was lead by Villard did not survive: drawings were often erased when the building was completed as they apparently served no further purpose. One of the pages of Villard's sketchbook is reproduced in figure 2.2.

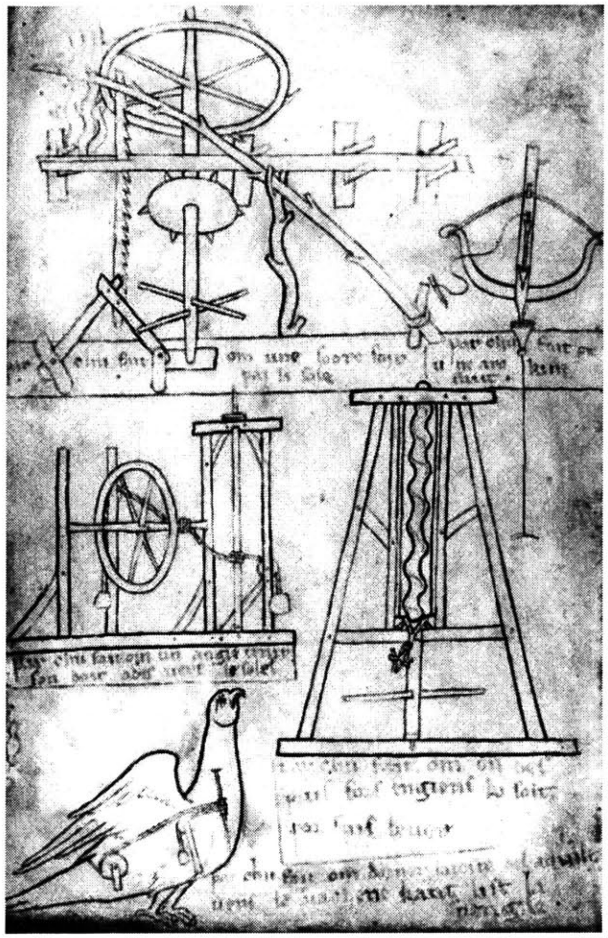

Figure 2.2 - One of the pages of Villard's sketchbook[4]

Henry Yevel was the king's master builder during the XIV Century in England. The peculiarities of this master builder are essentially related to the fact that, being part of the Royal service, he could work on various projects, not being limited by an attachment to a monastery. His offices were designated as follows[1]:

- In 1358 he is styled "Cementarius and apparitor working and ordering masons work".
- In 1365 he is "Director of the works".

- In 1378 a patent says "Director of the Works in the Art of Masonry at the Palace and the Tower"
- In 1390 "Surveyor of the Works".

Various records witness that at that time it was quite common to employ a designer and a builder as two separate entities, supporting this choice by stating that there was nothing strange in the idea of separating the functions of designer and builder. A document dated March 18th, 1395 states that the work for the Westminster Hall in England should be done "in accordance with the purport and form of a model made by the advice" of Yvele and given to the masons.

2.7 The design and drawings

"A noble building, indeed any work of art, is not the product of an act of design by some individual genius, it is the outcome of ages of experiment" [*Architecture*, W.R.Lethaby].

In the Middle Ages, as well as in earlier times, the decimal system was not familiar to designers or to builders. Therefore, the designer (position usually held by the master builder) found it difficult to work by calculation and preferred to use geometry. By means of geometrical figures, he could establish a coherent system of proportion. Each master used his personal measure and geometric methods, and the fact that, when a master substituted for another master, the design methods always changed, demonstrates that earlier drawings were not left behind. In this way every master could ensure a sort of "copyright" on his works[6]. Designers trusted in the inner harmony of the world fabric and believed that geometrical harmony helped in some degree to assure structural stability[1]. Moreover, structural beliefs were mostly based on experience or trials, leaving much room for creativity. Taking the example of Canterbury, the various combinations of pillars from east to west are obviously intentional experiments. As no design for complete buildings has survived, it can be assumed that drawings were produced section by section as the work proceeded and were never numerous. This methodology was implemented for the simple reason that many changes were made during construction, and completing design before construction would have been just a waste of time and resources. Sometimes, in fact, masters of the works changed their mind during implementation principally for two main reasons. The first reason is that they grew fearful of the load they were laying on the substructure, such as at Ely (England), where the naves, designed for a vault as shown by the shafting of the nave piers, have never received it. Secondly, sometimes a change in the style was in the air and the master desired to be at the forefront of new trends, as at Selby (England)[7].

As far as the plans go, they were usually drawn on parchment, which, being precious, was used and re-used several times. This is the main reason why very little of the cathedrals' drawings has survived.

2.8 The cathedral of Chartres (France)

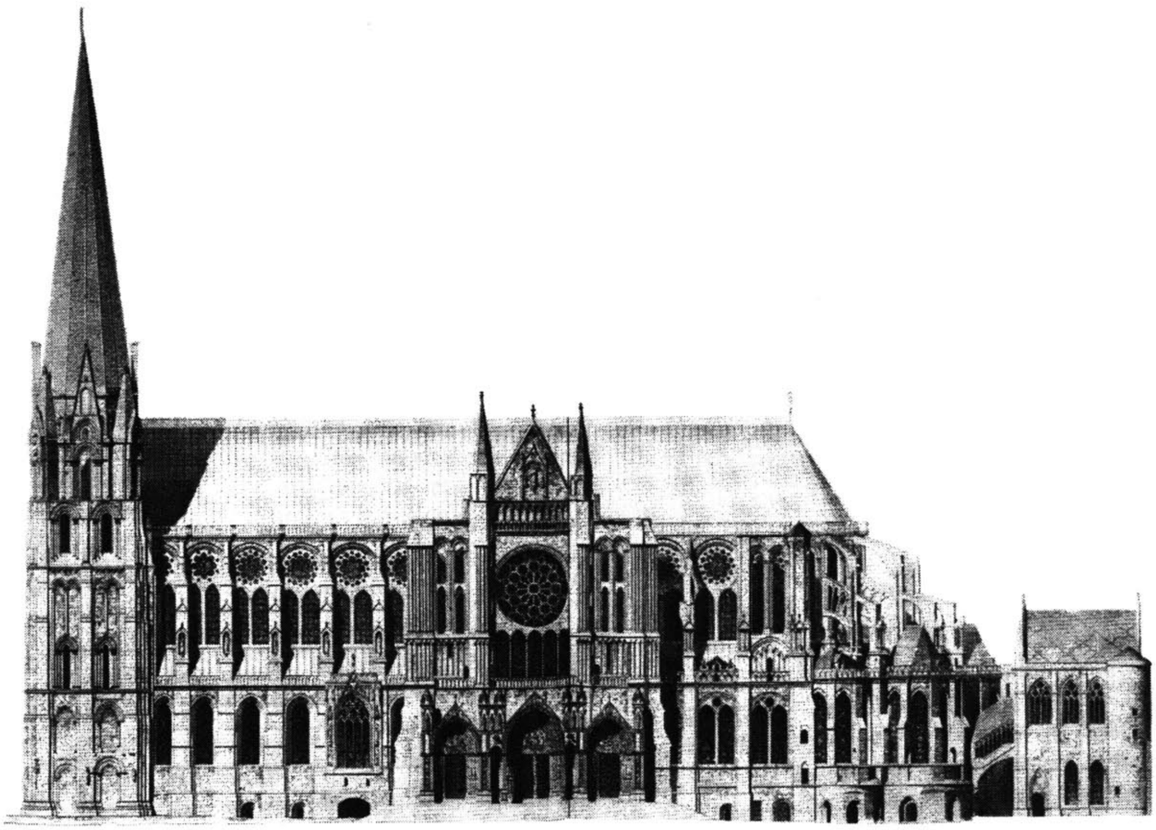

Figure 2.3 - The cathedral of Chartres (France)[2]

The cathedral of Chartres is one of the most outstanding masterpieces of the whole medieval architecture. The reason why this specific project was chosen as an example is that it was basically the work of one generation, having been completely rebuilt after the disastrous fire of 1194 in a very short period of time. Many books have been written about the beauty of Chartres, its architecture and history. Here, the scope is to analyze the contracting issues, as well as the figure of the master builder with respect to the whole organization of the works. "Though there are no documents or legends about the great masters at Chartres, we can in fact discover an enormous amount about them. We can read the story of the cathedral's construction stone by stone. By interrogating it carefully enough we can see the artists who made it, and enter into something of their spirit"[2].

2.8.1 The contractors

In-depth analysis of the building, reveals evidence that large mobile teams of masons who moved around the countryside from job to job built the cathedral. When the funds ran out they would leave the site in a body, with intact crews under a master, to find another project. Proof of this is found by isolating all the parts of the building that are different or show joints. A study carried out by John James shows that not only did the joints separate different periods of work, but different contractors as well. The individuality of the masters stood out very clearly: each of them had his own foot measure and systems of geometry. After that, it is easy to establish identities of the masters, to understand the nature of the design process and the extent to which the different contractors worked on the ideas of their predecessors, or changed them to suit their own preferences. All the misalignments and errors throughout the cathedral are witnesses to the lack of continuity in the direction of the work[6].

The exact chronology of the construction of the cathedral can then be established as well. Over forty different campaigns can be found, and most of the contractors seem to have worked on the job more than once, returning in a casual way as the accidents of unemployment and fund raising dictated. Since the construction lasted about forty years, it seems not unreasonable to assume there was an average of one campaign a year[2].

As far as the number of personnel working on the entire project goes, it is estimated that almost three hundred men would have been working on the cathedral at any one time, including those working at the quarries, the carters, and the carpenters. Each master would have had about thirty senior men under him, who represented the most skilled and trustworthy workmen forming the permanent and treasured part of the crew.

By observing each single piece of stone that is part of the cathedral and, in particular, the marks carved on them, many interesting things can be discovered. These marks are called mason's marks and represent the individual signature of the cutters. Although not much information is available about them, it can be stated, as a consequence, that the men at the quarry were paid by the piece rather than the day.

The masters that worked at Chartres were not local men, but the best masters to be found in the Paris Basin. These masters worked all over France, and also contracted cathedrals such as Mont St. Michel and St. Quentin. The many patterns found at Chartres may also be found throughout northern France[6].

To better understand the figure of the master builder at Chartres, the example of the master Red can be analyzed. Red arrived at Chartres in 1213 without having worked there before, and at that time only a few fundamental decisions were left for him. All the responsibility of the work was now on his shoulders. After having carefully examined the building, he probably ordered the carpenter to check the stability of all the woodwork left over from earlier campaigns, examined all the cranes, and designed the templets for the masons. Whenever something was to be designed, the procedure was to study and measure the existing work, then design by actually producing the drawings to be illustrated to the work force. Finally, he would check that the work was being done properly.

2.8.2 The client

At Chartres the client did not exercise much control over the contractors. This behavior, common to most of the Middle Ages' cathedrals, lead to little understanding of the building and to a lack of information given to the contractor about what had happened before. The main reason why this happened was that the client was more concerned about accounts than geometry, and was willing to leave all the intricacies and the concerns of physical construction to specialists[6]. In particular, at Chartres the clients exercised their authority to maintain a uniform interior, but no conditions were imposed on the outside, where most of the clues to the many contractors may be found[6].

A permanent supervisor to control the builders and to pay them was appointed by the Chapter. He would find the contractors, hire them and control their performance as well as supervising the administrative side of the works.

In a construction as long as the Chartres' cathedral (which, by the way, is considered a 'fast track' construction for that period), the clergy sometimes decided to change some original ideas, according to the architectural trends. There is evidence that one master was ordered to stop work when he reached a certain level: in 1210 the Chapter decided to reconsider the whole arrangement for the upper windows.

According to John James, the Chapter called for a competition to decide how the upper level of the church would be built. Masters from all around the Paris Basin would meet at Chartres to propose ideas and schemes. Finally, a decision was made, and it seems that master Ruby was chosen, as his corbels and his typical window details can be found in the next campaign. Ruby's solution is showed in Figure 2.3. The mobility of the crews meant that the clergy had a wide range to choose from, encouraging competition and the creation of new ideas[6].

Fortunately, not many changes occurred in the church during the centuries, leaving it almost like it was during the XIII century. Gradual changes, though, are still in progress; the only difference is that now the client is the State, which owns the cathedral.

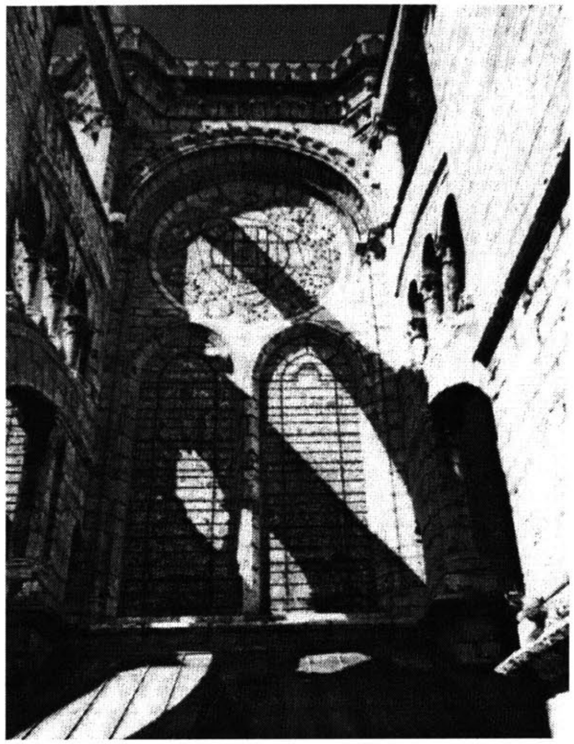

Figure 2.3 - The window design which won the competition in 1211[6]

2.8.3 The architect and the master builder

The figure of the architect has been defined in many different ways, since the time of Vitruvius. Common to all of these definitions is his total responsibility for the design and the structural stability[6]. At Chartres the figure of the architect was totally absent. The master builder was the architect as well and nobody was standing between the master builder who led the crews and the Chapter, or between the contractor and the client.

"The master made the decisions to change the geometry, the structure or the design. Not only did he control the detailing and the templets for the smaller items, but he controlled the larger ones as well. If we look closely at the changes that were made from one campaign to another, the only thing the client demanded was that the interior followed the one agreed format. And even that instruction was given only in general terms, without specifying either details or dimensions"[6].

The construction of the Chartres cathedral, as well as that of many other ones, was pursued with a "start-and-stop" method of contracting. Every team, under the leadership and supervision of a master, worked until the funds were available. The master would have to look for another contract as soon as he became aware of a lack of funds. The client may have been obliged to tell the master when he had only enough funds to last another month, and the master could then start looking for another job. When a representative of another job visited Chartres looking for a builder, the master would sign up, to assure continuity in his work and that of his crew. Even if, after that, more money was received by the treasury, he would still have to leave, having committed to another client[6]. This way of contracting, although complicating the works and delaying its schedule, made it possible to create a work of art from many hands, avoiding any potential architectural monotony. When, later in the 1250s, a new method of contracting was established that involved only one master builder for a whole project, the resulting architecture often proved to be less interesting[6].

2.9 Conclusion

A general view of the figure of the master builder in the Middle Ages has been provided. The environment to which a master builder was exposed, as well as an example of the development of one of the greatest projects of that time are provided too. The next chapter will focus on the design and build method of project delivery that is being applied nowadays.

2.10 References

[1] J.Rykwert,1966

[2] J.James, 1979

[3] I.Richards, 1968

[4] W.Swaan, 1969

[5] O.van Simson, 1962

[6] J.James, 1978

[7] R.L.Palmer, 1930

3. DESIGN AND BUILD

3.1 Introduction

The "design and build" method of procurement is now a well established form of completing projects in many parts of the world. The diffusion of design and build was made possible primarily because of its potential to reduce the costs of projects. However, it presents many other major advantages; some of them include the following[1].

- Design and build allows for continuous adjustment of the design during construction. This helps to reduce cost, allows risk to be managed more effectively, and leads to a flexible process in which optimization can continue until each element of the works is actually built.
- Design and build makes it possible for the contractor to have a closer relationship with the design team and vice-versa. In this way, construction issues are more relevantly taken into account, and design constraints are evaluated while choosing the construction methods.
- Design and build places detailed design responsibility with the contractor. This forces the contractor to understand more completely the works being constructed. Under traditional procurement, options are narrowed down to a single solution before a contractor becomes involved. The opportunity for the contractor to participate in scheme optimization is extremely limited.
- Preparing a design and build contract imposes a discipline on the Owner to identify the objectives of the project. Delivery of these objectives is then passed

to a contractor, who is best placed to decide how they should be realized.

These benefits can be significant, but they are not guaranteed. In fact, many projects do not suit design and build; unless the right conditions occur, the potential benefits will not be realized. These conditions include the following.

- Design complexity and scope for method innovation. Projects containing both design complexity and scope for construction method innovations are particularly suitable for design and build, as this combination maximizes the scope for a designer/contractor team to benefit by matching design and method for best possible results. Where neither condition pertains, the benefits of design and build diminish considerably.
- The promoter's approach to procurement. One of the commonest weaknesses in design and build contract documentation is over-specification. To achieve the benefits from this form of procurement, the promoter must be prepared to control the detailed design of the works. As a consequence, a good design and build contract should focus on objectives. It should express, without ambiguity, the essential characteristics which the completed works are to possess, and should say as little as possible about how they are to be achieved.
- The contractor's approach to design. Successful design and build contracting is an art in which the relationship with the designer is central to success. Starting the relationship late, or attempting to minimize the

designer's input will lead to disappointing outcomes. An integrated team is needed for best results, with both parties recognizing that an effective partnership will produce more and better solutions than either can deliver alone.

- Risks related to third party actions. Projects which suffer many and/or major third party interfaces, and in which the consequential risks can be better quantified by designing the works in detail, may not be suited for design and build. In this case, entering into partnerships with the third parties to share risk may yield better results overall.

In order to better understand and identify these benefits, it is necessary to undertake an in-depth analysis of the design and build method, and to look at the other existing forms of project delivery.

3.2 The different contractual solutions

There exists a wide range of solutions to the problem of how to arrange contractually for the implementation of a construction project. The persons most directly affected are the building client, who pays for the work, and the contractor, who performs it. The reasons for the existence of many contractual solutions lie in economic trends, in passing or recurring fashions, and in the nature of building itself. In addition, the client may be an individual, a partnership or a public or private corporate body. Consequently, contractors have developed various ways to meet the needs of different clients[2].

In the *traditional method* of project delivery, schematically shown in Figure 3.1, both the design professional and the contractor are retained separately by the client. The design professional's role is to develop a design plan in response to client-defined needs or goals, to weigh the alternative solutions, and to recommend a plan to the client. The clients' choices are then presented to the contractor by the design professional, who, during the construction phase, also guards the client against potential defects and deficiencies in the contractor's work. On the other hand, the contractor is expected to determine the most efficient and cost-effective methods by which the design intent can be achieved.

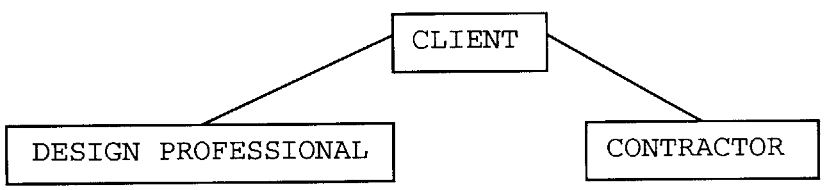

Figure 3.1 - The traditional method[2]

The *turnkey project delivery method*, shown in Figure 3.2, is characterized by the fact that the contractor provides all design and construction services for the project, including financing the project, obtaining permits, procuring the construction site, designing, constructing, operating and maintaining the facility for a certain period of time. The contractor then essentially turns over to the client the keys of a fully functioning and operating facility.

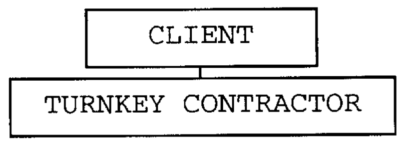

Figure 3.2 - The turnkey project delivery method[2]

The *construction management method* of project delivery became popular in the early 1970s, at about the same time as the design and build method. Both methods grew out of the client's desire to find more economical methods of project delivery. In construction management, however, the client hires an "outsider", or construction manager, to maintain objective control over the project's schedule and cost. The figure of the construction manager can be either an independent professional consultant or an individual within the contractor. Both arrangements add a fourth player to the traditional three-party structure, although the relationship between the client and the contractor may vary. A schematic of the structure of a project involving the construction manager is given in Figure 3.3.

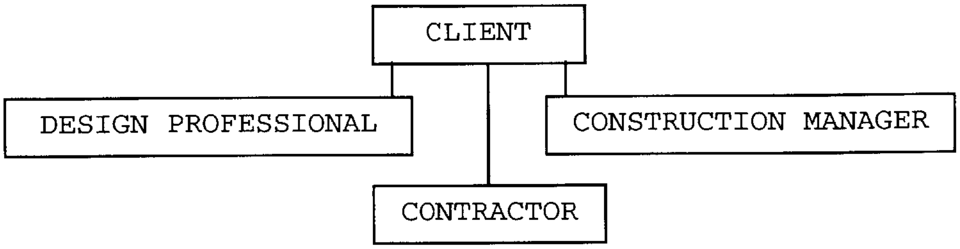

Figure 3.3 - The construction management method[2]

The last method of project delivery that is worth mentioning is the so-called *fast track construction.* In this case, construction activities start before design is completed. This method became popular in the late 1960s in response to the high interest rate and the need to reduce the overall cost of the projects. Clients realized that the total design and construction time could be reduced by performing those activities concurrently and not consecutively. Fast track construction, however, presents a greater risk than other project delivery methods. In fact, design documents are incomplete at the beginning of construction, and the design professional has no opportunity to coordinate the complete package of construction documents prior to their release to the contractor.

3.3 Design and build possibilities

The design and build method can be performed in an "hybrid mode". This means that any of the procurement methods discussed earlier can be combined with the design and build method according the needs of the entities involved. As a consequence, a project can be completed with a *design and build - construction management*, *design and build - fast track construction*, *finance - design and build*, or *client - design and build* method[2]. In any case, there are four basic organizational forms by which design and build services are provided to the clients. These forms differ based on the identification of the party who directly contracts with the client, or primary contractor[2]:

1. Design Professional as Primary Contractor.
2. Contractor as Primary Contractor.
3. Joint Venture of Design Professional and Contractor as Primary Contractor.
4. Design and Build Organization as Primary Contractor.

3.3.1 Design Professional as Primary Contractor

In the first case, the client contracts directly with the design professional for all design and construction services required to complete the project. The design professional will then decide to contract with a contractor for the construction works, still being responsible for both the design and the construction of the project. Moreover, he assumes financial responsibility for costs exceeding the contractual limit or guaranteed maximum construction costs. As far as the contractor's responsibilities go, he is not responsible to the client directly. Rather, he is responsible to the design professional.

3.3.2 Contractor as primary contractor

In this case, the client contracts directly with the contractor, who holds the responsibility of contracting with one or more design professionals to provide design services in the case that design cannot be provided internally. This is the most common type of design and build method, because of the typical large disparity in size between design and construction firms. As a matter of fact, a small design firm has fewer resources than a large construction firm and, as a result, may have greater difficulty competing for design and build projects. The responsibility of a potential failure in the project or an eventual delay are completely carried by the contractor with respect to the owner, even though the design professional is accountable to the contractor for any failure of the project's design.

3.3.3 Joint Venture of Design Professional and Contractor

Basically, here the design professional and the contractor enter into a joint venture agreement in which they both contract to the client for performing all design and construction requirements. The typical joint venture agreement is normally stipulated on a one-project basis, though often the same parties re-establish a partnership for further projects when successful projects have already been completed. In this case, both parties can take advantage of the established administrative, management and financial structures.

3.3.4 Design and build organization as primary contractor

A design and build organization is a single legal entity, which provides all project-related services, from design to construction. The organization may be owned by a single individual, called *sole proprietor*, or by a partnership other than a contractual joint venture. The main difference with the joint venture of a design professional and a contractor is that in this case, no subcontracting of any portion of the project occurs.

3.4 The client's perspective

The reasons why the clients often choose the design and build method as their preferred way of contracting are basically the following: reduction in total project delivery time and costs, single source of responsibility, inventive design solutions and reduction in project management stress. However, clients should also be aware of the disadvantages of the design and build methods, which can be basically related to the fact that there is the loss of the design professional as a truly independent professional advisor[2].

3.4.1 Reduction in project delivery time and costs

There are many reasons why design and build may make it possible to complete a project more quickly than other methods. First of all, there is a large reduction of the construction documentation, because the contractor may interact with the design professional by suggesting construction methods that are more suitable to the firm's experience, thus simplifying the documentation needed from the design professional. Secondly, collaborative decision-making performed by the design professional and the contractor allows a big time reduction, when compared to a traditional approach. In this case, the design professional must first determine an approach, and then either require contractors to competitively bid that approach or negotiate with one or more pre-selected contractors. Thirdly, schedule delays are often avoided by the frequently more relaxed and informal environment that is created within the design and build organization. Moreover, in a traditional project, any change during construction is typically handled in a sequential manner. However, with the better communication amongst designers and contractors, in the design and build method it is possible to cooperate and find a quick and effective solution to any problem. Moreover, there is higher motivation to resolve differences because responsibility for the success of the project rests in the hands of both the design professional and the contractor. The link between the discovery of a problem and the solution to it, is much closer in a design and build project, since both design and construction activities take place under one single roof.

Cost reduction is a consequence of reduction of the project delivery time, since time is money and the cost of borrowing money increases with the period it is borrowed. In addition, in design and build it is possible to reduce design costs, by spending less time preparing drawings and specifications and administrating the construction.

3.4.2 Single source of responsibility

The responsibility of all design and construction activities rests in the hands of a single entity, the primary contractor, regardless of the design and build arrangements. This represents a great advantage for the client, whose management and administrative burden is reduced. In fact, in traditionally structured projects, the client often plays the role of facilitator or coordinator between the design professional and the contractor: this task is eliminated using the design and build approach. Moreover, a single source of responsibility may protect the client from liability in certain situations, by limiting the exposure to claims by the contractor.

3.4.3 Inventive design solutions

The close relation of design professionals and contractors allows for potentially more inventive and creative solutions. Engineers with a design background are often little aware of construction issues and vice-versa, thus a team effort can lead to a better understanding of each other's skills, talents and constraints. Design and build teams work in close communication from the very beginning of a project, long before completion of the design professional's drawings and specifications, allowing the contractor to interact and integrate its knowledge and creativity into the final design.

3.4.4 Reduction of project management stress

Every project represents a big source of stress for the client. The client is mostly concerned about whether the project will be completed on time and on budget, and whether market trends will shift during construction, and have disastrous effects on the project's financial success. The design and build method, with respect to other traditional delivery methods, is more reliable regarding those aspects. The project management stress may also be reduced by the fact that the number of players whom the client must interact with is reduced, and the responsibility rests in the hands of one single entity.

3.4.5 Loss of independent professional advisor

Perhaps the only notable disadvantage for the client in the design and build arrangement is the loss of the design professional's role as an independent advisor. Although this is true for all forms of design and build contracting, the arrangement of design professional as primary contractor is the one where the loss is occurs to a lesser extent. This disadvantage is based on the assumption that the design professional cannot represent the client fairly if he or she has financial interests in the project. This belief is strongly supported by the main American design professionals' associations, such as the American Institute of Architects (AIA). However, this view is not shared by contractor's associations, such as the Associated General Contractors of America (AGC). The concept of the design professional as independent professional advisor is deeply rooted in the U.S. culture.

3.5 The contractor's perspective

The main reasons for a contractor to choose the design and build method for contracting are the increased control over the project, the minimization of risk and project uncertainties, the improved communication with the design professional and the opportunity to increase profits. However, even from the contractor's point of view, some weaknesses may be found, such as a greater responsibility for the acts and omissions of the design professional and possible gaps in insurance coverage[2].

3.5.1 Increased control over the project

Contractors usually respond to design decisions and are not involved in the design process at all. With design and build, they can actively participate in the design activity. The next step is then to offer design services routinely as part of a spectrum of project delivery services.

3.5.2 Minimization of risk and project uncertainties

In a traditional design-bid-build project, the design professional specifies the construction issues without consulting with the contractor. These specifications are often incomplete or are then completely changed by the contractor, which could have its own preferred construction methods, depending on its experience and skills. Moreover, it is likely that the contractor has very little time to review the documents before the bid is submitted. In the design and build process, the contractor is in direct communication with the design professional from the beginning in order to discuss how the project can best be completed. The design/build team is chosen in particular based on its willingness and ability to meet project requirements, thus reducing the project's uncertainties.

3.5.3 Improved communication with the design professional

No sets of construction documents, regardless of how detailed they are, is absolutely complete. There will always be the need for additional information or clarification. The contractor needs communication with the design professional, in order to better understand or critique its specifications. When a design/build team is formed, the cooperation itself represents a great means of communication, probably the best. In addition, if the design professional is directly involved and responsible for the construction issues as well, he or she will be more willing and effective in cooperating and helping the contractor with its issues.

3.5.4 Opportunity to increase profits

The opportunity for contractors to increase profits in a design and build project arise for the following three main reasons: controlling the selection of construction materials and methods, reducing design- and construction-related activities, and responding quickly to unanticipated changes. The reduction of activities may be related to the fact that in a design and build project the amount of documentation that is necessary for the contractor to be informed about the design professional's intentions is less than in a traditional project. In fact, the contractor usually needs some general information before specific decisions are made at the time it is necessary. Other construction-related activities normally performed by contractors and design professional separately, may now be performed in conjunction, saving time and money.

3.5.5 Responsibility for acts and omissions of design professional

In traditional contracts, contractors are liable only as far as the "failure to perform their work in compliance with good building practices and according to the information contained in the design professional's drawings and specifications" are concerned. Normally, they are not responsible for acts and omissions directly related to the design professional. However, in some design and build contracts, the contractor may be liable for acts or omissions for which the design professional is responsible.

3.5.6 Gaps in insurance coverage

The contractor and the design professional should always make sure that each of them only bears the risks associated with its own activity. However, even then it could happen that, in a lawsuit, the loss exceeds the ability of the negligent part to pay, with a consequent loss from the other party too. As a consequence, all parties involved in a design and build project should "consult with a qualified professional advisor concerning the risks and liabilities associated with the various design/build arrangements"[2].

3.6 The design professional's perspective

Just as for the other parties involved in a design and build process, there are advantageous reasons for the design professional to commit to a design and build contract as well as disadvantages. As far as the advantages are concerned, the main ones are a greater control over project quality, the opportunity to increase profits, the field experience, a greater credibility with clients, and a reduction of the incidence of claims by contractors. The disadvantages include the responsibility for the acts and omissions of the contractor, the gaps in the insurance coverage, the large start-up costs, the decline in status[2]. These factors are analyzed separately.

3.6.1 Greater control over project quality

This is the main reason why most design professionals choose the design and build method, as they are able to directly and actively participate in all aspects of the design and construction process rather than merely being observers during the construction phase. There are greater opportunities for on-site design decisions and design changes during construction. Using the design and build method, "direct communication between the design professional and the contractor not only enhances the design professional's knowledge of construction matters in general, but speeds the decision-making process"[2].

3.6.2 Opportunity to increase profits

The design professional may increase the profits in the design and build process in four different ways[2]:

- *Reducing design services*. With a close relationship with the contractor, the design professional only provides essential information about the requirements of the project through the drawings. All other decisions can be made and communicated to the contractor in much less formal ways.
- *Assuming an equity interest in the project*. Profits may also be increased by "assuming an *equity interest* in the project, and then watching that share increases in value over time"[2]. This approach is often utilized in condominium projects, where single units are easily identifiable and evaluated.
- *Protecting against market fluctuations*. When the construction market experiences a depression period, design firms' profits decrease following the decrease of the demand of design services. Contractors, on the other hand, suffer a depression period to a lesser extent, as a single project can generate the same amount of dollars as several design projects can do. Thus, "a design professional who practices design/build may protect against market fluctuations by generating income from construction operations to cover the reduction in design

activities. This protection is of particular importance to those design/build firms that are controlled by design professionals"[2].

- *Increasing marketability and expanding the client base.* The marketability of a design professional engaged in design/build may increase by offering to the client not only design, but also construction services. As a consequence, the design and build team is able to expand the single client base to one that is the sum of the design professional's client base and the contractor's client base.

3.6.3 Field experience

Traditionally, design engineers spend years in a variety of in-house tasks, without having the opportunity to go in the field and see their design projects come true. On the other hand, contractors often complain about the design output, which may lack the construction knowledge that is necessary to easily implement the design professional's ideas. "The opportunity to work at the contractor's side during construction of the project, to see first-hand the actual construction tasks that must be performed, and to hear the questions and concerns raised by the contractor on a variety of matters, including the information contained in the drawings and specification, can be an invaluable experience. The design professional often discovers simpler, more constructable and, occasionally, less expensive ways to build"[2].

3.6.4 Greater credibility with clients

Clients are more likely to trust a design professional that is engaged in design and build, on its knowledge about the art of design and construction together. Furthermore, the increase in the design professional's credibility reduces the client's anxiety, providing a more efficient way of delivering the project.

3.6.5 Reducing the incidence of claims by contractors

Most claims made by contractors against the design professional are related to mistrust, lack of communication or the desire for retribution. In design and build projects, these circumstances are reduced when "the parties perceive themselves as working for common goals and pursuing common interests"[2].

3.6.6 Responsibility for acts and omissions of contractor

In a design and build arrangement the design professional is liable not only for its own acts and omissions, but also for those of the contractor and for its failure to build in accordance to the construction documents. In addition, in some instances, the design professional's insurance does not cover the added risk.

3.6.7 Gaps in insurance coverage

It may happen that the design professional's insurance coverage is limited to anything that is related to the design activities. Each party should make sure and obtain proof that the other carries adequate amounts of coverage.

3.6.8 Large start-up costs

A project's initial costs are much larger for a design professional involved in a design and build business, than for a design professional working in a more traditional line. The labor, equipment and plant costs are likely to be larger than a typical design facility. "A design professional going into the design/build business may suddenly be responsible for providing substantial office space and labor forces, and accommodating intensive equipment demands"[2].

3.6.9 Decline in status

When a design professional engages in a design and build business, he or she certainly will be viewed differently than a party that is retained just to provide professional advice. The client often is more interested in the project's budget and schedule and will sometimes look to the contractor as the major authority in these aspects. "The design professional's tradition image of upholding public trust and confidence may also seem threatened by the design/build arrangement. This is because having a financial interest in the design/build firm prevents the design professional from fulfilling its customary obligations to the public"[2].

3.7 Procurement methods for design and build

A client that is willing to use the design and build method of procurement has to go through three key steps. The first is an analysis of the project, in order to make sure that the design and build method is suitable for its specific case. If it is, the client must then select the proper design and build arrangement. Finally, the client must select the design and build organization. The procurement process typically starts with a pre-qualification process, during which the prospective design and build teams submit their credentials for the client's evaluation. Then, the design and build team can be accepted to participate in the actual selection. This selection can follow three different methods: negotiation, bidding, or design competition[2].

3.7.1 The pre-qualification process

In most cases, clients request a *Statement of Qualifications* from teams interested in participating in the selection process.

In the private sector, a *Request for Proposal* is issued by clients to parties that, to their knowledge, could be interested in the project. "The *Request for Proposal* typically contains information about the size, scope, and complexity of the project, the client's requirements and budgetary considerations, selection criteria and method of evaluation, and the requested form and content of the party's proposal".

In the public sector, the law usually requires an *Advertisement for Bid*, which is published in certain newspapers and contains information about the project and the rules for submission of bids.

According to Timothy R. Twoney, typical qualification statement provided by a design and build team describes the following:

- The team's experience on prior projects.
- Proof of adequate financial capacity.
- Lists and resumes of key people who will be involved in the project, with special regard to design and build experience.
- Current and projected workloads.
- Ability to secure required performance, labor and material bonds.
- Design and construction quality on prior projects including design and build.
- Ability to complete prior design and build projects within schedule and budgetary constraints.

The client at this point evaluates all teams' characteristics and identifies those that meet the minimum qualifications required for the project. These team will participate in the final selection.

3.7.2 Negotiation

In this method the client, based on interviews or negotiations with representatives of each team, selects a team that is believed to be best suited to implement the project. There are two different approaches within this method[2].

In the *Direct Selection* approach, the client establishes a ranking of the best design and build teams who have pre-qualified. Then the client and the first ranked team discuss and review the project's requirements, the team's approach to design and construction, and the terms and conditions of a potential agreement. If they do not arrive at a mutually satisfactory agreement, the client will then negotiate with the second ranked team. This process continues until an agreement between the client and one of the design and build teams is reached. A weakness of this method is the fact that the selection is not based on a comparison among the design concepts of all teams. This weakness is eliminated by the use of the second approach, *Comparative Selection.* In this approach, three to five teams are selected from those who successfully pre-qualified. Each team is then required to submit design concept proposals which are then evaluated by the client. The extent to which the proposals are detailed depends on the project, the client and other political aspect. However, the goal is not to present the client with a selection of detailed designs from which to choose, but to make it possible for the client to analyze the team's ability to meet its needs and the project's requirements.

3.7.3 Bidding

In the bidding method the client chooses a design and build team based on the lowest priced proposal. The bidding is similar to the comparative selection negotiation approach, with the difference being that in this case the teams are required to submit *cost proposals* together with the design concepts. There are three different kinds of bidding[2].

Lump Sum Bidding is characterized by the submission of a bid in the form of a lump sum for all services, costs and expenses regarding all aspects of design and construction.

In *Cost-Plus Bidding,* the client pays the design and build team for the costs incurred in connection with the project, plus a fee that represents the team's profit.

The last type of bidding is the *Guaranteed Maximum Price*. The design and build team establishes a maximum price for all design and construction of the project. "The design and build team is compensated, as it would be on a cost-plus project, for the actual costs incurred in connection with the design and construction of the project, plus a fee. This compensation is subject, however, to a ceiling, or guaranteed maximum price, beyond which the client is not obligated to pay" [2].

3.7.4 Design competition

A third method for procuring design and build projects is the design competition, which is similar to both the negotiation and bidding methods. If the submission requires a cost proposal, then this method assumes the characteristics of the bidding approach, with the difference that "the design submission in a competition is typically far more developed than the more conceptual design proposal in the negotiation approach".

3.8 Øresund tunnel: making a success of design and build

It often happens that the use of design and build as the procurement method makes it possible to implement innovations both in construction and in design, that would not be possible if design and construction had been procured separately[1].

3.8.1 Overview on the project

"The Øresund tunnel is a 3.5-km-long road/rail immersed tunnel, forming part of the Øresund Link between Copenhagen in Denmark and Malmö in Sweden.

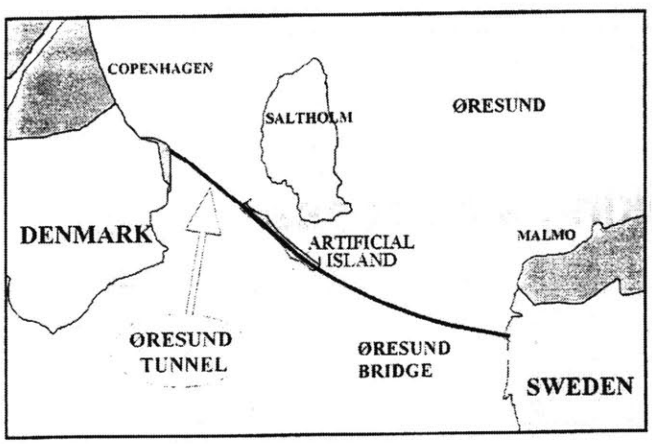

Figure 3.4 - The Øresund tunnel project[1]

The tunnel and the adjacent approach works are being constructed on behalf of the Øresundkonsortiet (a client company set up and owned jointly by the Danish and Swedish governments) by Øresund Tunnel Contractors (ØTC)"[1], a joint venture comprising five European contractors. Design of the tunnel is being performed on behalf of ØTC by UK consultant Symonds.

The principal elements included in the contract are:

- 5 km of 2x2 lane highway;
- 4 km of twin track railway;
- 500 m of approach ramp on the Danish coast;
- a 300-m-long tunnel portal structure on the Danish coast, incorporating about 100 m of cut-and-cover tunnel;
- 3.5 km of immersed tunnel;
- a 300-m long tunnel portal structure emerging onto an artificial island in the Øresund;
- 700 m of approach ramp on the artificial island.

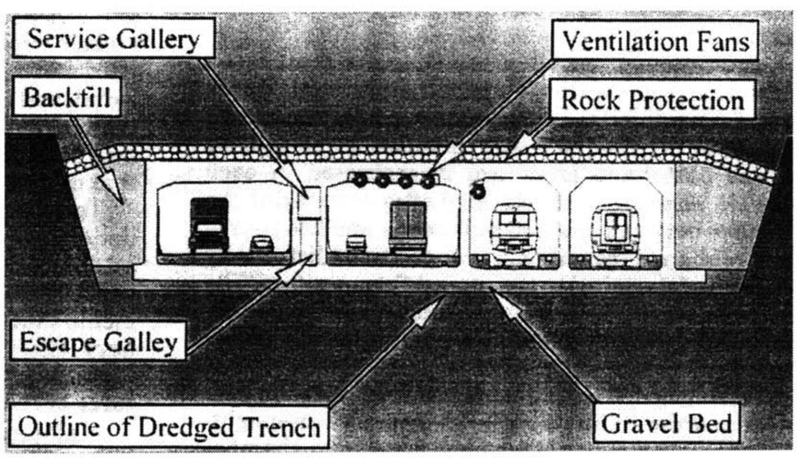

Figure 3.5 - Section of the tunnel[1]

3.8.2 Pre-Tender collaboration and Tender Process

"ØTC made a first, and crucially important, contribution to the collaboration which followed, by appointing their designer some six months ahead of invitation to tender, before the joint venture itself had fully established" [1]. By doing this, the initial building of the team between the two parties could get started, as well as an early exchange of ideas about the tunnel construction methods. During the Pre-Tender process, the designer/contractor team analyzed the possible options for the tunnel, comprising both steel and concrete solutions.

The Øresundkonsortiet (ØSK) invited tenders for the Øresund Tunnel in October 1994. Four design and build teams were invited to tender, and the European Union's tendering procedures were chosen to assure fair competition, even though at that time Sweden was not a member of the EU. Four months was the time allowed to the teams to prepare an outline design for the complete tunnel project and an estimate of the costs. By the time of the submission (February 1995), ØTC had completed the basic structural design of the tunnel and all approach structures, as well as identifying the principal construction stages.

A peculiarity of the ØTC team was that the design team was based in the UK, far from the contractors. To avoid any communication problems, a small liaison team (6-8 people) was created and established in the contractors' offices in Copenhagen. Its tasks were to facilitate understanding of the contractor by the designer, and vice-versa. Communication was also achieved by means of regular meetings in Copenhagen attended by senior representatives of the design firm, and by the presence of a design project manager who worked alternate weeks in Denmark and in the UK.

3.8.3 The tunnel construction method

The conventional construction method for immersed concrete tunnels is characterized by the preparation of a large temporary excavation for the construction of the tunnel elements. Once the elements are complete, the excavation is then flooded, in order to be able to float them out to their final position. For this reason, the excavation has to be below the water level. For a tunnel as large as the Øresund, a huge excavation would have been needed, as well as extensive groundwater lowering for a period of several years. An alternative construction method was necessary. In order to find the best solution, several brainstorming sessions were organized by the ØTC construction specialists and the Symonds' designers. Through this process, the final unique construction method was developed. It consists of "factory construction of all tunnel concrete without resorting to a large excavation, casting of each tunnel segment in a single 30-hour concrete pour, full off-line prefabrication of reinforcement cages, and transportation of completed tunnel elements some 300 m before immersion in water" [1]. Some of the benefits of this new and innovative method include faster construction, continuous concrete construction allowing uniform labor demand, reinforcement handling and assembly off the critical path, elimination of early age cracking without recourse to artificial cooling of the concrete, indoor performance of all reinforcement, formwork and concreting activities. Moreover, the overall cost of the project was reduced by the economic use of labor, fast mechanical handling of reinforcing steel, the elimination of artificial cooling, and a significant reduction in construction time, even though the capital cost of the special tunnel fabrication facility was huge. Although the total method itself was new, "each feature consisted of an established construction method, and the contractor judged correctly that the risks inherent in such innovation could be managed through careful attention to design of the facility" [1]. The risk related to the project, in fact, turned out to be smaller than in a traditional tunnel construction, as shown in Figure 3.6.

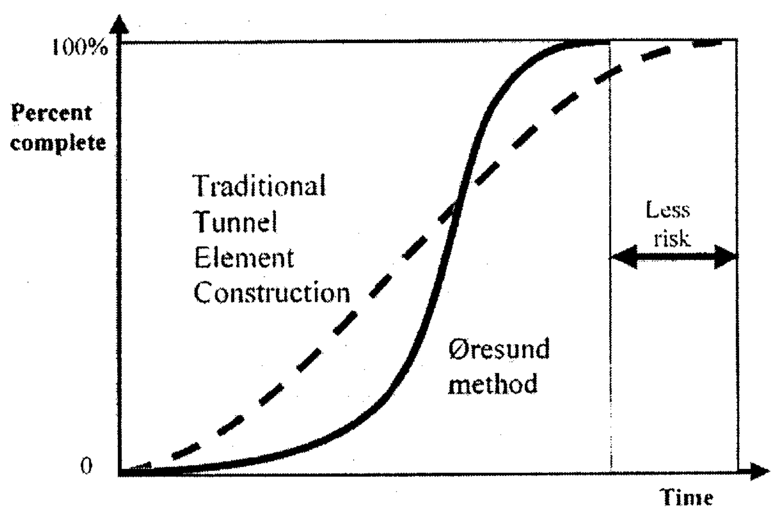

Figure 3.6 - Construction program and risk[1]

3.8.4 Tunnel structure and joints

Each tunnel element was chosen to be 175 m long, in order to minimize cost and number of elements. This choice was driven by the constraints given by the concrete pour size, the thermal stresses, the segment joint costs and the need for repetitive construction cycles.

In conventional concrete tunnel design, "the final tunnel alignment relies on the accuracy of immersion joint construction. Strict tolerances are specified and these are met through a two stage process whereby a steel end frame is cast into the end of the element, and a secondary steel plate is welded onto the frame after concreting" [1]. Because of the unusual dimensions of the Øresund tunnel, this method was not applicable. A new and innovative way of aligning the tunnel segments, as well as an alternative joint design were therefore developed jointly by the contractors and the design professionals".

3.8.5 Design and build considerations

Immersed tunnel projects "are often well-suited to design and build due to their scope for construction method innovation and the degree to which design is method-driven. This procurement method has now been used for immersed tunnels in many parts of the world" [1].

In the Øresund tunnel project, the design and build method made it possible to implement a number of innovations that would have been very unlikely to emerge if design and construction activities were performed separately. The tunnel construction method represents a great example of the potential benefits that can be achieved using design and build. The method chosen "depends on the design of the tunnel structure being significantly customized to suit the construction method, whilst at the same time, the construction method is developed with design optimization as a primary objective" [1]. The integration of design and construction concerns is typical of immersed tunnels, because of the complex process of precasting, transport, immersion, jointing and backfilling that every segment has to undergo before reaching its final condition[1]. Such an ingenious and innovative method of construction would have never been developed by a design firm without the help of a contractor. Similarly, a contractor would have never developed such a method on a build-only basis, without extensive re-design of the structure.

The opportunity of optimizing both the tunnel elements' length and the geometry would never have arisen under the traditional procurement approach. In fact, the variables affecting these choices are mainly construction-related. As far as the joint design goes, neither of the joint design innovations had been identified nor developed during the tender phase. The problems arose during the final design phase, and the cooperation between the contractors and the design professionals was a key aspect in the development of these innovations.

The Øresund tunnel project has clearly demonstrated that, under the right circumstances, the design and build method can provide significant benefits for the promoter of a major project, as well as for all of the other parties involved.

3.9 Conclusions

All the different possibilities of delivering a project are analyzed. Advantages and disadvantages of the design and build method from the client's, the contractor's and the design professional's perspective are discussed. An example of a successful project carried out with the design and build method is provided. The next chapter will focus on how the lessons learned from the master builders can be applied to design and build and what are the obstacles that may occur in the process.

3.10 References

[1] Chris Marshall, 1999.
[2] T.R. Twomey, 1989.

4. CRITIQUE

"Just as today there are great contracting firms that undertake to build a dam in Asia, a bridge in Africa, a hydro-electric generating plant in South America, so in time past there have had to be companies of some sort whose organization, resources, equipment, experience and knowledgeable personnel could make possible the most important building operations of the time. The Pont du Gard for Roman times, and the great French thirteenth century cathedrals for Gothic times commanded the most consummate skill and the most enlightened practices of the period" [James Fitchen].

Construction in the 21st century is evolving faster and faster. What took five years to design and build in the sixties, now probably takes only four. Information technology is becoming an issue within the construction industry that cannot be denied. Time and schedule constraints are now much more of a priority. Still, quality is a must. The essence of modern project management can be synthesized in the triangle shown in Figure 4.1.

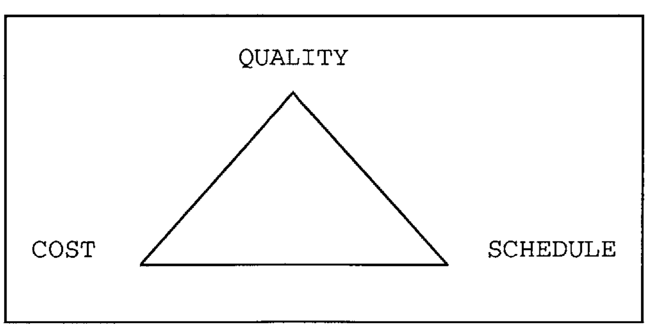

Figure 4.1 - The essence of project management

Within the construction industry, meaning both design firms and contractors, the trend is to move from a static-oriented organization to a corporation system. Construction firms are expanding into different markets, such as public and maintenance services or telecommunications. Those that are more successful rely on the policy of decentralization, where the decisional power and the responsibility rest in the hands of people closer to the works. On the managerial side, more professionals coming from different fields such as finance or electrical engineering are becoming key people for construction companies. Construction people are no longer the only professionals in contractor organizations. The trend, again, is to move from a solid and static organization to a dynamic and meritocratic organization. In other words, the construction industry is trying to be in step with the changing nature of the business in the 21st century.

However, to construct is still "to build; to put together different parts to form a whole"[1]. This definition is valid now as it has always been and always will be. In the Middle Ages, "the major task of a Master was to visualize what was to be done, to determine the method and then to organize the teams so that his intentions would be carried out. This has been the indispensable task for the architect/builder at all times. Be he Roman or Feudal, capitalist or socialist, the demands of a great edifice would have imposed the same disciplines. The ways of organizing a large body of men to a constructive purpose with the maximum efficiency and the minimum of waste are much the same in any age and for any task. It is not for nothing that Fitchen placed organization first among the attributes of the great contracting firms" [2].

Certainly, the means of achieving the final product for a project are changing, as well as the overall goals and objectives. But the concept is the same. In particular, analyzing the design and build method, it is possible to see many similarities with the role of the master builder in the Middle Ages. In design and build, design is carried out together with the construction thanks to a concurrent and collaborative effort of the design professional and the contractor. The master builder was both the design professional and the contractor at the same time. Therefore, his works may be considered as design and build projects. The difference is that at that time no other way of project delivery was possible, because the complexity of a cathedral and the typical uncertainties of such project required that decisions be made step by step. According to John James, "the decisions came from the immediate situation rather than from an exactly premeditated plan. The building was a concept in time: the work of the moment, element by element, was the major governing reality. The medieval way of building made it possible for the cathedral, like for a tree, to evolve from the generalized concepts of the times into its own rich and particular personality in a way that would not have been possible under our more controlled conditions".

A major difference between the way of carrying out a project in the Middle Ages and nowadays is, in fact, that kind of "control" which John James talks about. For a master builder, the fact of being able to work on the design and construction of a cathedral at the same time meant that he was able to express his art and creativity according to his inspiration. While the erection of the cathedral was being pursued, he could have a physic perspective of his work and, therefore, be able to evaluate the potential of the future decisions with more awareness. Today, the scope of design and build is essentially to reduce cost. It is not primarily to be able to end up with a better product. The fact that this method gives more opportunities to improve the characteristics of a building or infrastructure is secondary.

In the construction of the cathedral of Chartres one of the master builders, Scarlet, operated in the following way, as reported by John James: "The windows have been set out anew each time, so that they precisely reflect the unique conditions around them. The geometric process was the same, yet no common templet was made that would do them all. The master designed each one as if it was for the first time. We would not do that today. We would standardize where Scarlet would not. He believed that each part of the building should precisely reflect the situation around it. No standardized unit could do this". It is fascinating to understand how not only during all the different campaigns the master's style would stand out, but also how each master, as in the example of Scarlet, would apply non-standardized systems. Nowadays different campaigns would mean loss of time and loss of money, so they are avoided to the highest extent. If we really wanted to apply that method to our age, we could think about a modern building designed successively, for instance, by Le Corbusier, Mies van der Rohe and Frank Lloyd Wright[2]. The major contributor to the design would inevitably have been Le Corbusier, and the other masters would have had to adopt his plan. The result would not have been chaotic. Whenever one of these architects designed an addition to an older building he worked with care to preserve the earlier work. Creative work without some sense of unity through it is not art, which is why even under medieval contracting conditions the masters developed a technique to ensure some sort of unity.

If this whole issue of rotation and change of design professional and contractor was possible, "today the building industry would organize a series of conferences to 'unify' and to 'rationalize' the contractual process; but we should not assume that medieval people would think of doing this. We are in an age of management and technocratic control, and above all we look for orderly and easily administrated solutions which require coordinated management. The results show in the ordered monotony of our office buildings and suburban blocks of land. Fortunately medieval man had little urge for this sort of thing. Only at the centre of political power did medieval builders approach our controlled and repetitive work in the giant military constructions which we can still see in Richard's

Welsh castles and in the town walls of Carcassone and Avilla"[2].

For this reason and for many others it is difficult to compare our age and the Middle Ages construction-wise. To clarify this point it is interesting to refer to John James when talking about the cathedral of Chartres: "When you spend four or more decades on a great work, both ideas and fashions change, even in sacred architecture. The model of 1194 may have been completely up to date, but it still would have been the work of one man and his time. Men and times change. Imagine the situation today. Suppose we had begun to build in 1960 to the best ideas available, and it is going to take us well into the 1990s to complete. By the time we are half-way up or so we are going to look back at the design of the sixties with some disdain. Our lifts are faster, our air-conditioning better, and we use less plain glass and more sculptured concrete. So it was in the Middle Ages, and that's why the triforium and the clerestory levels are usually more "advanced" or Gothic than the aisles".

Looking back with today's perspective, it is quite amazing to realize how well the cathedrals' projects were organized. "A considerable city project today seldom has more than 150 men at a time on the job, though for short periods towards the end of the work there may be more. However, in modern projects, the workforce has to be increased to produce the services such as lift and air conditioning, much of which is manufactured in factories far from the site. But in Chartres, all these men were engaged in the common task of cutting and erecting the one material - stone"[2]. And they did a perfect job. Sometimes, of course, small crews of stone workers were assigned to quarries where they carved certain pieces of stone to be sent to the site, providing the basis for what now is commonly called the prefabrication method.

A last issue that must be analyzed in order to understand the construction world of the Middle Ages and relate it to today's world is the relationship between the client and the builder. According to John James, "there is no clear demarcation between the roles and responsibilities of client and builder as there is today". Today, clients look for the best way to complete a project as far as cost and schedule are concerned. Most of the times a consultant is hired in order to control the works. Even in the design and build method, the client still has decisional power and, in most of the cases, some knowledge of the project. In the Middle Ages, the client did not have that knowledge and trusted the master he had appointed. The objective of building a cathedral was mostly to build a place for the community, a signature monument for the city, and a sacred construction. It was not a project pursued to make money.

There is a common aspect that stands out in all of the previous considerations: the environment of the 13th century is quite different from what exists in the 21st century. It is the environment that made the medieval projects be quality and art driven, and the 21st century's projects be time and cost driven. The proof of these assumptions is to be found in the fact that in the Middle Ages quality and art were pursued as long as there was money available for the project. When the funds were over, the works stopped until more money was found. This would not be possible in our century. Projects are now implemented with budget constraints and need to be completed as soon as possible. However, greater quality must always be achieved, and many lessons may be learned from the medieval master builders.

The kind of quality that is needed in the construction world of the 21st century is not necessarily related to art. Rather, there is a need to look for a quality that is defined by functionality, flexibility and aesthetics of built facilities.

Design and build can offer the possibility of opening the doors on the opportunity for greater quality through the concurrency of design and construction. Looking back at the master builders' works, this way of conceiving quality stands out very clearly. The master builders had an extraordinary capability of facilitating the ideas within the whole process of designing and building a facility.

The master builder of today certainly requires a different set of skills and capabilities, due to the different environment he is exposed to. He has to be more focused on the new potentials of the Information Technology applied to construction, for example. He also has to be able to understand the 21st century's needs of the clients. But, fundamentally, the master builder of today is similar to the medieval master builder in his leadership ability, expertise, creativity, communication skills. Both today and in the works of the Middle Ages, something fascinating may be found: the tenacity, the commitment, the sacrifice of generations of men who dedicate their lives to create the best possible facilities to be used by the community and to serve the people.

4.1 References

[1] *Cambridge International Dictionary of English*

[2] J.James, 1978

BIBLIOGRAPHY

A.A.V.V., *Cambridge International Dictionary of English*, Cambridge University Press, Cambridge, 1995

James, John, *Chartres*, Routledge & Kegan Paul, London, 1982

James, John, *The contractors of Chartres,* Vol. I, Vol. II, Mandorla Publications, Dooralong, 1979

Marshall, Chris (1999), *The Øresund Tunnel - Making a Success of Design and Build,* Tunneling and Underground Space Technology, Elsevier Science Ltd., 14, 355-365

Palmer, R. Liddesdale, *English Monasteries in the Middle Ages,* Constable and Company Ltd., London, 1930

Richards, Ian, *Abbeys of Europe*, The Hamlyn Publishing Group Ltd., Feltham, 1968

Rykwert, Joseph, *Church Building*, Hawthorn Books Publishers, New York, 1966

Swaan, Wim, *The Gothic Cathedral,* Doubleday & Co. Inc., New York, 1969

Taylor, Michael J. (2000), *Return of the master builder*, Civil Engineering, ASCE, 70(3), 41-43

Turner, Dennis F., *Design and build contract practice*, Longman Inc., New York, 1986

Twoney, Timothy R., *Understanding the legal aspects of design/build*, R.S. Means Company Inc., Kingston, 1989

Von Simson, Otto, *The Gothic Cathedral*, 2nd Edition, Bollingen Foundation, New York, 1962