Universitat Autònoma de Barcelona

Prehistoric House and 3D Reconstruction:
Towards a BIM Archaeology

Ivan Campana

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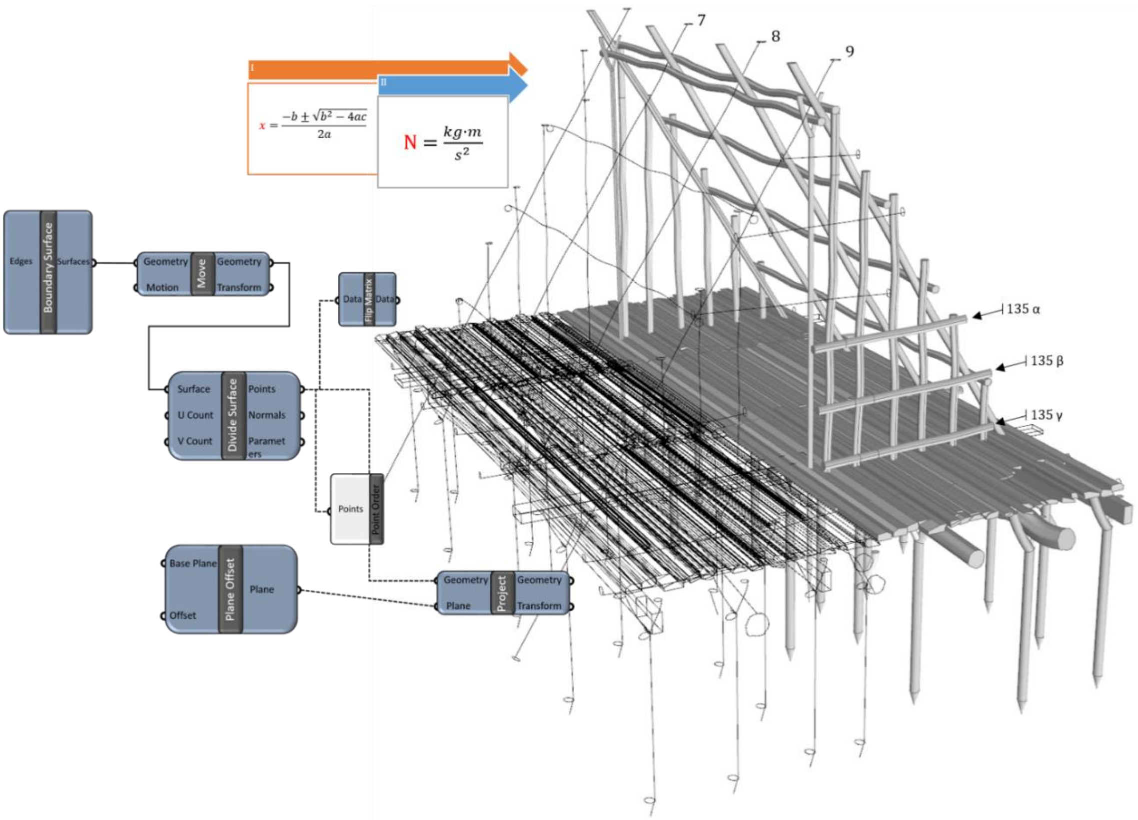

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Prehistoric House and 3D Reconstruction: Towards a BIM Archaeology.

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Thesis submitted for the degree of Doctor in Prehistoric Archaeology

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To my family.

"We shape our buildings; thereafter they shape us. „

Sir WINSTON CHURCHILL

"A human being should be able to change a diaper, plan an invasion, butcher a hog, conn a ship, design a building, write a sonnet, balance accounts, build a wall, set a bone, comfort the dying, take orders, give orders, cooperate, act alone, solve equations, analyse a new problem, pitch manure, program a computer, cook a tasty meal, fight efficiently, die gallantly. Specialization is for insects! „

ROBERT HEINLEIN, TIME ENOUGH FOR LOVE (1973)

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INTRODUCTION

The main aim of archaeology is the understanding of the past through the explanation of material observables discovered during the excavation. In order to achieve this task, archaeology always looks for the most advanced and useful technology. Over the past 20 years, advances in computing have allowed archaeologists to visualize their data sets in increasingly sophisticated ways. An example is computer-aided drafting (CAD) that, among other things, has allowed new ways of visualizing, and hence, analysing archaeological objects and spaces (Shelley 1996). However, as for the manual drawing and the photographs, there is a limitation: early CAD approaches limited the analysis of architectural data in a two dimensional space (Levy and Dawson 2006). On the contrary, cultural features such as houses and other buildings are defined by a volumetric region of physical space that should be represented using a minimum of 3-dimensional (henceforth 3D) (Barceló 2014). Only a 3D representation of built spaces allow the detailed study of such factors as wall sloping, roof height and the distribution of light and shadow, playing a role in mediating the organization of domestic space (Pramar 1973; Lourenço 2001; Papadopoulos and Earl 2009, 2014; Ching 2014; Brughmans *et al.* 2015). As spatial analysis is an important means of examining social organization in archaeology, we need a 3-dimensional approach to activity area research, through the application of computer modeling and virtual reality techniques (henceforth VR) (Barceló *et al.* 2000; Dawson and Levy 2004; Levy *et al.* 2004; Wilson 2011; Dunn and Woolford 2013; Forte 2014a). Within a high-dimensional representation (even 5D in certain circumstances), archaeological features can be explored from many different perspectives. This has the potential to provide new insights into the functional analysis of past objects, houses and spaces: how they were built, how they were used in the past, how they have been preserved in the present. This implies investigating their function, their form and shape, and the social-cultural processes behind their creation, and so on (Barceló and Moitinho 2012; Papadopoulos and Sakellarakis 2013). Creating a model of an archaeological artefact, or simulating it, and then placing it inside a high-dimensional environment could also help in the study about the built space and its relations with the natural environment (Kantner and Hobgood 2003; Kantner 2010; Robertson *et al.* 2006).

In this research, I will illustrate our efforts to build and validate a high-dimensional visual model of the pile dwelling from the Early Neolithic site of La Draga (Girona, Spain), explicitly built to explain archaeological remains and to understand the logic of built spaces in a remote past. An innovative methodology based on BIM (Building Information Module) has been used to create the model and expand its explicative capability.

OBJECTIVES

I think it is important to spend a few words about why we decided to rely on Virtual Archaeology to undertake this investigation. We decided to use it because it is a powerful combination of tools that, if handled properly, helps the archaeologists in reconstructing the past, providing new points of view, aiding with the observation and analysis of the evidences and overcoming problems that, with the traditional means of investigation could be impossible or too hard to solve.

Virtual Archaeology allows you to see what you are studying, to handle it, to test it, and to do countless things otherwise impossible thus saving both time and money and keeping the artifacts safe. And because the human being is a sensorial being, and our brains work on the basis of inputs, the more inputs we receive, the more information we can process, and this could lead to new deductions, new insights. Needless to say that observing and testing an object, causes much more inputs than just staring at an endless list of data or words. Having this in mind, we decided to investigate whether it was possible to use Virtual Archaeology theory, techniques and technologies to analyse the architectonical wooden elements found at La Draga and to find out whether was possible or not, to reconstruct the aspect of the Neolithic pile dwellings, to make inferences depending of the particular form and shape of the reconstructed buildings, and most importantly, to test the reliability of such reconstruction.

The following questions describe the goals of this research:

- ***Is it possible to produce a reliable and accurate reconstruction of one of the Neolithic pile dwellings of La Draga archaeological site using both the archaeological data at our disposal and 3D technologies?***

  One of the main objective of this research is to show how 3D technologies could be used in order to construct a reliable 3D model of prehistoric architecture even if the archaeological data are scarce.

- ***Can the comparison with other Neolithic pile dwelling settlements and ethnographical analogies help us in explaining the archaeological evidences found at La Draga?***

  Archaeological data are, usually, fragmentary especially in prehistoric archaeology. Sometime they are not enough to understand the "ways of the past". However, sometimes, ethnographical analogies can help us in this sense. In this research, instead of "fantasize" about the pile dwellings forms, or deducting them just by comparison with other archaeological sites, we decide to use, among the other tools, ethnographical analogies to determine, whenever possible, form and function of every house elements.

- ***Is it possible to describe and analyse a prototypical Neolithic house using analytical categories coming from modern architecture and using a specific and standardized language?***

  Too many archaeological publications concerning prehistoric houses (and not only) lack, almost completely, a precise architectonical definition of built spaces: e.g. the rafter, the purlins, and so on. We have worked to solve this limitation by studying how architecture divides built space into different planes (e.g. vertical plane, horizontal plane etc.), and creates a specific ontology of functional terms and concepts. It makes easier the definition of the different parts of the house, their function and the analysis. We have used this ontology to describe a particular example of prehistoric architecture.

- ***Is it possible to create a generic descriptive model of the prehistoric timber house components?***

  Once described the house's elements using the new ontology of functional terms and concepts, we have create a general model suitable for all kind of timber houses in different historic periods.

- ***It is possible to build a Building Information Model (BIM) process starting from the data acquired during the excavation?***

  Even if still in a preliminary phase (alpha version), we have implemented the conceptual model of the prehistoric timber house into a Building Information Model (BIM), providing a blocks definition for expanding the explanatory model and generalize our initial findings. In the last years, BIM technologies have proved their potential even if in archaeology they still lie in an embryonal state. Our goal is to set the base for a functional BIM that would fit not only with the site of La Draga but also with all the archaeological sites in general.

Research Methodology

The research method, aimed to reconstruct one of the pile dwelling of La Draga, has been designed bearing in mind the scarce information available, even in conditions of an extremely careful and well designed archaeological excavation. It consists of the following parts:

- **Collection of archaeological data from the site**: that is the collection of all the information about the architectonical wooden elements and possible parts of built structures, founded so far around the Banyoles lake in North-eastern Iberian Peninsula.

- **Collection of archaeological data from other Neolithic pile dwelling settlements around the world**: even if each site is "a world of its own", their analysis can help to identify the role of the architectonical wooden elements found at La Draga and providing a starting point for our reconstruction.

- **House architecture analysis**: how architecture defines and analyses the house, which its key elements are and what are their roles. This new approach to a prehistoric architecture allows to "give a name" at each specific part of the pile dwelling and to understand the relation between them and the different planes composing the house.

- **Ethnographical research**: because the archaeological data is often partial, ethnographical research could help us "joining the dots". It comes about that, at times, modern human groups (usually in less-developed areas) are still using ancient building techniques or/and production activities. The study of these cases can help in shedding light on still blurring aspects of the ancient societies and their technologies.

- **Building principles and the analysis of physic forces**: meaning the collection of all those information about the pile dwellings construction and the physic forces that interest such structures. Even if the data came from study on modern buildings, they are still essential because physic forces are continuous in time as well as some requirements, like the characteristics that a soil must have to be suitable to the construction of a pile dwelling.

- **Data synthesis and creation of a virtual model**: the data obtained with the precedents steps has been analysed trying to understand the function of the different architectonical wooden elements preserved so far and the possible forms of the prehistoric pile dwelling. The outcomes have been elaborated as a 3D model created using Rhinoceros 5.

- **Creation of a preliminary BIM process**: we have been working on an alpha version of a Building Information Model, defined to handle all the data collected so far and update the explanatory model when new data will be available in the future. The BIM is implemented as an interactive computer program that will keep the model always up-to-date: each time we will integrate a new data or a new value the whole model will change accordingly. Furthermore the BIM will allows us using the virtual model in order to undertake all the future analysis we shall need, like stress analysis.

THESIS OUTLINE

This thesis consists of **7 chapters** arranged as follows:

After the introduction and the objectives statement, **Chapter 1** provides a description of the theoretical background of this study: it is based on a discussion about the genesis of Virtual Archaeology and its ramifications including purposes, pros and cons of this new approach to Archaeology. We went through Functional Analysis and Reverse Engineering exploring the relationship with Virtual Archaeology. Finally an overview of the "new entry" in Archaeology, the BIM.

Chapter 2 describes the methodology we used in our reconstruction. For this reason, this huge chapter is divided into 5 parts: Functional Analysis and Built Space; Ethnography and Archaeology; Neolithic house and relation with modern examples; Architectural analysis of the house; the Physic behind the pile dwellings. **The first part of Chapter 2** describes the relationship between Built Space (or Built Environment) and Archaeology and the general principles of Functional Analysis in Philosophy of Science. This chapter presents some prominent theories and insights about these themes. **The second part** is about the relationship between Ethnography and Archaeology, the evolution of Ethnoarchaeology, and how ethnographical analogy help interpreting the past. The chapter also includes a description about how we used ethnographical analogy, in our research, in order to overcome problems connected to the interpretation of archaeological evidences. **The third part of Chapter 2** gives a general vision about different kinds of Neolithic houses around the globe, in order to display the great diversity of architectonics at these early times, even when technology was poorly efficient, and the social division of labour did not determine the complexity of built spaces. In this chapter modern pile dwellings are shown in order to illustrate how, in some cases, modern pile dwellings could resemble the ancient ones, helping archaeologists to make hypothesis about "how" the ancient pile dwellings were built and "why". These ethnological and architectonical similarities, when the archaeological data is scarce or unclear, could be used to deduce or speculate the form and technique of the ancient pile dwelling. **Part four** presents an analysis of timber buildings using an innovative ontology based on modern architectural definition of house parts. The built space (the house) has been divided into different planes, and inside each one, we have identified the essential constituting elements. An intent to create a general descriptive model has been also undertaken, with the aim of creating a general descriptive model, not only suitable with the Neolithic houses at La Draga but also with houses from other sites. Finally, **the last section of Chapter 2** illustrates which are the physic forces that affect a pile dwelling, a point almost lways forgot when reconstructing these kind of buildings. Even if the study shown in this chapter refers to modern pile dwellings, the physics forces and their action where the same in Early Neolithic. This chapter also shows the different kind of wooden degradation that could affect a pile dwelling.

Chapter 3 describes the archaeological site of La Draga, the wooden elements found during the excavations, which have been interpreted as architectonical parts of the buildings that may have existed at those times.

Chapter 4 illustrates the reconstructive process followed in order to reconstruct the houses of La Draga: from “dissecting” the house using the ontology defined in chapter 2, to the reconstruction of its elements. Moreover, the relationships between the different elements and parts of the house have been examined in order to show how they work and how they interact with each others. Finally, the chapter illustrates how each reconstructive steps has been undertaken using, among the other things, the architectonical, ethnographical and physical tools, described in the previous chapter.

Chapter 5 describes the steps followed in order to create a functional BIM that would fit not only with the site of La Draga but also with all the archaeological sites in general. We describe its functions and we detail the way such a general model can be applied to the particular case of La Draga.

Chapter 6 presents the achievements of this entire research that go beyond the "simple" reconstruction, introducing a new way to define and analyse the ancient buildings and describing the important physic aspects that have to be taken into account upon embarking on a reconstructive process. **Chapter 6** also includes the description of what I called the "***Three Little Pigs Theory***", describing how buildings having similar shapes, dimension etc. may not only have very different meanings and functions but also different response to the same physic forces, which is why comparisons based uniquely on "similarities in shapes" should be avoided.

In **Chapter 7 – Annex,** all the programs used during four years of investigation are presented.

1

THEORETICAL BACKGROUND

“*Space… the final frontie*r. „

J.T. KIRK, STAR TREK (1966)

1.1. FOREWORD: 3D, VIRTUAL REALITY AND VIRTUAL ARCHAEOLOGY

The first use of the term “virtual reality” date back to 1938, when the dramatist and theatre director Antonin Artaud (1896 – 1948) used it in his collection of essays titled “*Le Théâtre et son double*” to define the illusory nature of characters and objects in theatre. The original expression "*la réalité virtuelle*" was translated as “*virtual reality*” in the English version of the essay “*The Theater and its Double*” published twenty years later (1958).

Among the earliest hypermedia and virtual reality systems, we can mention the Aspen Movie Map, which was created at MIT in 1978. By the 1980s the term "virtual reality" (henceforth VR) was popularized by Jaron Lanier, one of the modern pioneers of the field (Lanier 1992). In the late 1980s he led the team that developed the first implementations of multi-person virtual worlds using head mounted displays, as well as the first "avatars," or representations of users, within such systems. Shortly after its discovery, VR began to be increasingly used in archaeology and both theoretical and methodological issues have been discussed (e.g. Reilly 1989; Reilly and Shennan 1989; Sims 1997; Fulk and Steinfeld 1997; Barceló *et al.* 2000; Forte 2000; Niccolucci 2002; Lopez Bendicho and Grande 2011; Pujol-Tost 2017).

From the 80s onwards, the development computer visualization allowed an approximation to 3D visualization through geometric perspective and object rotation. The use in archaeology of such approaches marked the beginning of a new era in the archaeological studies. The use of computer graphics, or 3D, to create models of ancient artefacts dates back to the early 1980s (quoted in Levy *et al.* 2004; Ask 2012).

Among these firsts simulations there are the John Woodwark's reconstruction of the Temple of Sulis Minerva in Roman Bath (Fig.2) for the BBC (British Broadcasting Corporation) (Lavender 1990; Woodwark 1991), the reconstruction of the Saxon Minster at Winchester (Heywood *et al.* 1984; Colley *et al.* 1988)**.** At the Computer Applications in Archaeology 1990 conference, Reilly presented an animated 3D computer model of a hypothetical excavation, the first example of applying solid modelling technology to archaeological research (Reilly 1991, 2013).

Among early applications, it is worth to mention the computer reconstruction of Paris (Collins 1993), the virtual reconstruction of the Dresden Frauenkirche (Germany), destroyed by Allied bombing raids in 1945 (Collins 1993), and the reconstruction of the Hakusa "keyhole" tombs (Kanagawa prefecture, Japan), the Mausoleum of Emperor Ojin (Osaka prefecture, Japan; Fig.1) and the village of Yoshinogar (Kyushu Island, Japan) undertaken by Ozawa (1988, 1993, 2002; Ozawa and Kaway 1991).

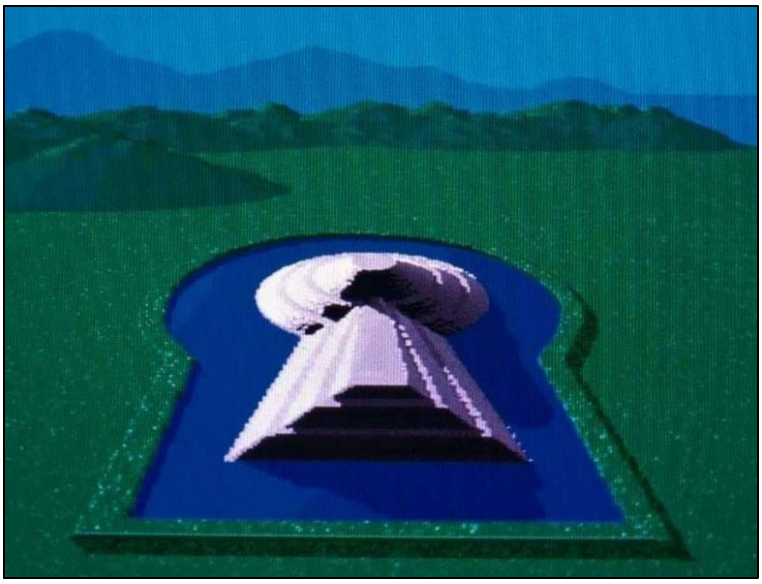


Fig.1: The first virtual reconstruction of Emperor Ojin's Mausoleum (Ozawa 2002).

Although the accuracy and realism of these early models were constrained by limitations in computing power and by the software available at the time, these early models nevertheless proved to be useful tools for visualizing archaeological data in a 3D context.

Fig.2: John Woodwark's reconstruction of the Temple of Sulis Minerva in Roman Bath (https://www.romanbaths.co.uk/roman-temple).

In his article titled “Towards a virtual archaeology" (Reilly 1991), he used the term VA to describe:

> *“The way in which technology could be harnessed in order to achieve new ways of documenting, interpreting and annotating primary archaeological materials and processes, and invited practitioners to explore the interplay between digital and conventional archaeological practice”.*

The proliferation of 3D modeling techniques in archaeology is in part an answer to the omnipresent necessity in archaeology to archive an overgrowing amount of data and to create the best medium to communicate those data with a visual language (Forte and Pescarin 2006; Forte *et al.* 2006; Economou and Pujol-Tost 2011; Pescarin *et. al* 2011; Stanco and Tanasi 2013; Pescarin 2014). From this point of view, the archaeological 3D modeling turned out to be a method of recording all the archaeological data in a more complete way than traditional photography and drawing. Forte described VA as a “*process of acquisition, restoration and re-presentation of archaeological data assisted by computers*” (Forte 1997).

Today, thanks to advances in the 3D technologies, not only we can built far more sophisticated and realistic models of archaeological artefacts, but we can also simulate the effects of environmental factors such as lights, shadows, candle smoke, fog and dust. The progress has been so great that it is now a mistake to refer to “3D” visualization or 3D graphics. Technically, when adding texture and rendering a virtual reality element we are going beyond three dimensions, so we should speak of 4D, 5D and so on.

Why need “virtual” computer models of archaeological data? What is the purpose of this technology? Most importantly, those models should allow us to understand human activity in relation with ancient objects and built spaces.

A majority of these computational visualizations of archaeological elements are meant to serve as means of communicating archaeology to a wider audience, rather than being made for research purposes (Hermon 2012; Ask 2012). According with Rasmussen (2011) the visualization is a fundamental starting point for the interpretation of archaeological material. Hermon (2012) points out that cognitive psychology, as well as education research, shows that a visualization tool, if properly designed, facilitates understanding and perception of information. This means that, when it comes down to the explanation of archaeological data, computer visualization models allow a direct and real time comparison between the geometrical characteristics of the investigated context and the different explanatory hypotheses formulated during the investigation. Moreover, this process of visualization can lead to a re-evaluation of previous interpretations that depends on the understanding of an archaeological material. Research in cognitive psychology has also shown the positive relationship between visualization ability (Ekstrom *et al.* 1976) and the use of visualization tools thus perceiving the information in a more appropriate way (Hermon and Kalisperis 2011; Pujol-Tost 2016). As pointed out by Barceló, Forte and Sanders (2000), the key concept is virtual: an allusion to a model, a replica, the notion that something can act as a surrogate or replacement for an original. VR allows the 3D visualization of concepts, objects or spaces and their contextualization (Roberts and Ryan 1997): it gives a visual framework in which data can be displayed. Through VR, it is also possible to interact with data organized in 3D (Frischer *et al.* 2002) and it is also possible to transform the information, making it more accessible to the human eye and thus more easily perceptible, and enhancing perception in the context of its interrogation (Hermon 2011). As soon as these new technologies began to spread, archaeologists explored their potential as visualization tools for heritage conservation, education and research (Pescarin *et al.* 2005, 2011, 2014; Pujol-Tost and Economou 2009).

1.2. Is there any "Virtual" Reality? Limitations of the approach

Even if in the last decade the potential of virtual reconstruction has been recognized in archaeology (Ryan 2001; Ryan *et al.* 2002; Hermon 2008; Hermon *et al.* 2005; Hermon and Nikodem 2007; Niccolucci 2012; Cerato and Pescarin 2013), virtual reconstruction, as a field of archaeological research, is still an undefined discipline. One of the main cause is the complexity and variety of technologies involved in virtual reconstruction: digital acquisition, spatial-enabled databases, metadata enrichment, and 3D modeling. Even so the scientific aspects, like archaeological record fragmentation and context diversity, are, however, the hardest to deal with (Bakker *et al*. 2003; Doerr 2003).

The debate about the VR is not only a technical issue but it also deals with philosophy and the "existential" sphere (e.g. Heim 1993, 1995, 2000, 2001, 2014; Turkle 1996, 1997, 2005, 2016; Rheingold 1991, 1993, 1998, 2016).

One of the strongest positions in this debate is, probably, Jean Baudrillard thinking. The philosophy of Baudrillard presents itself as a meditation on the status of the image in a society addicted to ''*the duplication of the real by means of technology*'' (Poster 2001). In his most notable book, "*Simulacra and Simulation*" (1981), Baudrillard argues that moderns systems of representation have undergone a process in which the signified has lost touch with the signifier that now only points to other signifiers with the "real" long gone. This means that there is no longer any distinction between reality and its representation. This concept of "the real" is one of the most challenging concepts in Baudrillard's theory. Intuitively we tend to distinguish what happens in the real world from what is represented to us. We know that what we see on television is not the real world but rather a representation of it. However, Baudrillard thinks differently. He uses the concept of "Simulation". A simulation is an event that "stages" an actual event and recreates its conditions and even experience. A simulation is like real life, only it is not. Usually we think we can tell a simulation from an actual occurrence, but Baudrillard's definition of the concept argues the simulation is not something that follows the real, but rather a "real" which does not stem from any other source or origin. A simulation for Baudrillard is not something that disguises itself as the real, but rather something which eliminates the actual "real", the real which is distinguished from its representations. When Baudrillard describes western culture's move away from the real he argues that what we are losing is a construction of the real. For Baudrillard, what we think is the real is always in fact a simulacrum of the real. Therefore, and according

Baudrillard, our society has reached a stage in which there is no longer any distinction between reality and its representation. Baudrillard defines this state as “the third order of simulacra”. This condition is the final step of a process and Baudrillard identifies three orders of simulacra describing the passage from a clear definition between reality and its copies to the absence of any distinction between reality and its representation. These three orders of simulacra are:

- First order: the image (or the copy) is a clear counterfeit of the real. The image, be it a novel, a painting a map etc., is recognized as just an artificial representation of the reality, a place marker for the real. Baudrillard associates this order of simulacra with the Renaissance in in which the attempt to accurately represent reality was the attempt to ratify its existence regardless of representation.

- Second order: here the distinction between image and reality began to blur. Baudrillard, following the theories of Walter Benjamin (1935), connects this order with the industrial revolution of the 19^{th} century and indicates the mass production as the main cause of change. Mass production misrepresents and masks an underlying reality by imitating it so well, thus threatening to replace it (e.g. photography). The original object loses its meaning in relation to its copies. However, there is still the belief that criticism and/or political action can assure the emerging of the real.

- Third order: it is associated with the postmodern age. The role are now inverted and we facing a precession of simulacra meaning that the representation precedes and determines the real. Any differences between reality and its representations vanish; there is only the simulacrum. According to Baudrillard, the real is constructed through its opposition with representation but, since the simulation breaks this distinction down, we can no longer claim that the truth is anywhere to be found in some objective world.

Therefore, in the Baudrillard's philosophic view, the real only pretends to be authentic, a stable and objective originless reality, when in fact it is nothing but the product of the symbolic trade of signs in culture. For Baudrillard, there is no longer any real difference between the real and the imagined, between the world and its representation.

This debate raises the problem of "truth". From Baudrillard criticism, we deduce that the main handicap in using "computer generated images and models" as surrogates of archaeological explanation is, precisely, their main apparent advantage: their high degree of realism by which they are supposed to substitute the originals. Any visualization is an interpretation (Ask 2012), and therefore we cannot substitute direct observation with visualizations.

In relation to this, Clark (2010) underlines the lack of declaration of the level of accuracy contra hypothesis of different parts of many archaeological virtual models, as well as the importance in accounting for the sources that influenced the creation of the virtual model. This forms the base of a vast debate about the concept of "reconstruction" and how the use of this term can be problematic and inappropriate (e.g. Barceló *et al.* 2000; Forte 2009; Clark 2010; Pujol-Tost 2011; Baker 2012; Pletinckx 2011, 2012; Rasmussen 2011). Usually the term is used to define representations of the past based on archaeological material and results, either made virtually, drawn, imagined and built in full-scale (Clark 2010; Rasmussen 2011). The use of this term is misleading because it implies the idea of actually having the possibility of re-constructing the past. We should take into account that a model is just a tool to understand a complex phenomenon but it is always a simplification. A model is not to be seen as the endpoint of research (Clark 2010). According to Forte (2009):

> "*A simple correspondence virtual archaeology = reconstruction of the ancient world seems, in some terms, reductive, or, otherwise, oversized, utopian and reductive because it seems finalized to the methods of structural architectural re-composition and not to the study of processes and relations between architecture*

environment- organisms. Utopian because reconstructing the ancient world is interesting as method, but not realizable in a single process".

Baker (2012) and Pletinckx (2012) suggest the term visualization as substitute of the term reconstruction:

> "*The goal of visualization is not to show an accurate image of the past, but to provide the viewer with visual arguments for the hypotheses of the researcher, while as a researcher being aware of and accepting inevitable uncertainty of interpretation*" (Baker 2012).

According to Barceló (2001) then:

> "*Visual models are then "interpretations" of real data, and it should be made evident how one gets from the perceived reality to the explanatory model. A model cannot be true or wrong, because it does not belong to reality. It is a projection from theories, used to know if our hypotheses are true, wrong, probable, or mere possible. Consequently, a scientific theory must be composed of models and hypothesis, linking models to reality*".

Despite this ongoing debate, there is still little standardization regarding the documentation of sources and interpretation processes leading to the creation of a virtual model. However, there has been attempts to create guidelines, such as:

- **The Declaration of Lund** (Sweden) in 2001, thought to promote the digitalization activities, especially in the cultural area (museum artifacts, archaeological excavations, historic documents, and so on), as way to preserve the cultural heritage and to propagate it among the citizen through the education and tourism (Lopez Bendicho *et al*. 2017).

- **The London Charter** (2006) for the computer-based Visualization of Cultural Heritage. This chart seeks to establish the requirements necessary to verify that a 3D visualization of cultural heritage is intellectually responsible and solid, as would be incumbent upon any other research method. The main objective and accomplishment of the London Charter was to overturn the principle of authority in the creation of virtual models according to which, depending on the inventor of a given model, it enjoyed more or less scientific standing. The authority principle has been replaced by the scientific method, according to which all virtual models must feature a set of data and information (metadata and paradata) facilitating their verification and evaluation by independent experts (Beacham *et al*. 2006; Denard 2013). It is important to point out that the London Charter is not limited to a specific discipline but rather aims to serve a whole range of disciplines and branches of knowledge, spanning the Arts, the Humanities and Cultural Heritage, provided that they employ 3D visualisation in the development of their respective research and diffusion projects.

- **The Ename Charter** (2008): This Charter was the first international text ratified by ICOMOS (International Council on Monuments and Sites) to recognize the importance of using virtual reconstructions in the field of archaeological heritage stating, in Article 2.4 that:

  "Visual reconstructions, whether by artists, architects, or computer modelers, should be based upon detailed and systematic analysis of environmental, archaeological, architectural, and historical data, including analysis of written, oral and iconographic sources, and photography. The information sources on which such visual renderings are based should be clearly documented and alternative

reconstructions based on the same evidence, when available, should be provided for comparison".

In its final form, the charter highlighted seven distinct principles seen as essential to this wider interpretive involvement in heritage and conservation activities: Promoting access and understanding; Reliable, broad-based information sources; Attention to setting and context; Preservation of authenticity; Planning for sustainability; Concern for inclusiveness; Importance of research, training, and evaluation (Silberman 2007, 2009).

- **The Seville Principles** (2011), International Principles of Virtual Archaeology, represent a specification of the London Charter. While the London Charter includes a set of recommendations applicable to cultural heritage in general, the Seville Principles focus their attention solely on archaeological heritage, as a specific part of cultural heritage (Lopez Bendicho 2011, 2013).

Other important documents emphasising the fundamental role of sensitive and effective interpretation in heritage conservation that are worth to remember are: the *Venice Charter* (1964); the *Nara Document on Authenticity* (1994); the *Burra Charter* (1999); the *International Charter on Cultural Tourism* (1999) and the *Principles for the Conservation of Heritage Sites in China* (2002).

1.3. The problem of reconstruction. Testing the model

Indeed, a major problem with the current methodology is the difficulty of representing and dealing with uncertainty (Demetrescu 2015). However, this problem does not belong to just virtual reconstructions but it is a "classical problem" in archaeology (Gros 1985; Medri 2003; Manacorda 2007).

Even if documents like the London Charter or the Sevilla Principles have highlighted the principles of scientific visualization and the need for the formalization of re-constructive processes the situation remains still largely fragmented when it comes to methodology, both in terms of data transparency and common standards (Beacham *et al*. 2006; Denard 2013). As well described in "*From CVR to CVRO: the Past, Present and Future of Cultural Virtual Reality*" (Frischer *et al*. 2002) the main problems of the virtual reconstructions are their credibility and validity. In the same paper, the authors suggest that the interpretive/reconstructive process of model creation consists of three steps:

- verify sources
- analyse their reliability
- interpret/integrate data with the missing parts

The models produced following these three steps should also show the evidence of this process using, for example, signs meant to identify those elements corresponding to interpolations, additions and conjectures.

Despite these efforts, the situation remains heterogeneous. Approaches dealing with uncertainty in archaeological reconstructions can be found in the works of Sifniotis (Sifniotis *et al.* 2006, 2010) and Strothotte (Strothotte *et al.* 1999a, 1999b). There are methods meant to represent uncertainty in reconstructions (Kensek 2007), chronological uncertainty (Pang *et al.* 1997; Zuk *et al.* 2005), typological details of the image sources (Dudek and Blaise 2004; Blaise and Dudek 2009), uncertainty charts representing ambiguity in virtual reconstructions (Pollini *et al.* 2005) and interactive visualization solutions (Bakker *et al.* 2003; Borra 2004; Bonde *et al.* 2009). However, one of the most common solutions in the management and visualization of reliability is what is generally known as the "*generative layers with query-able elements*" approach. This approach consists in the segmentation of the model based on the typology and the supposed "degree of certainty" of the sources used in the reconstruction (usually represented with a colour scale). There are different "versions" of this approach, meaning that a standardized version does not yet exists.

Another method has been developed by Niccolucci and Hermon (2004). According to them, reliability and uncertainty of represented archaeological data can be solved by implementing a fuzzy set approach. For this reason, Niccolucci and Hermon established a scale for reliability based on the interval [0, 1] where 0 means "totally unreliable" and 1 means "absolutely reliable". They define the creation of archaeological model in terms of:

> "*A stepwise process in which one starts from an initial model* M_0*, possibly empty, placed at position* x_0*; at step* n *a new model* M_{n+1} *is built from* M_n *adding a new detail* m_{n+1} *in an absolute position* x_{n+1}".

Every detail and every feature increase the completeness of the model and makes it more explanatory. Needless to say that the more details and feature we have to reconstruct the more the reliability of the model is reduced. M_0 is the new model or the archaeological evidence; *m* represents each new detail that the user may add at any time, for example, the first wall of a structure will be m_1; *x* are vectors containing all relevant information to put objects in place, uniquely determining their position in space, in such a way that m_1 will be placed in position x_1. When all details be added, we will have a new model or M_k.

FUZZY LOGIC is a branch of mathematics based on fuzzy set theory. The latter, first proposed by Zadeh (1965), introduces special sets, called fuzzy sets, having a characteristic function that may vary between 0 and 1 and not only assume the two extreme values as for ordinary sets.

According to these authors, reference has to be given to the model because the model is not reliable by itself, only when it is referred to a specific problem. It is important to highlight that this approach does not consider any time frame, so the model is assumed to be temporally reliable. The reliability function *r* can be considered as a fuzzy truth value of models that uses the minimum of the fuzzy truth function f of its operands. The problem of reliability is then split into three components. First, absolute reliability *r(a)* taking into account the reliability of the object per se. Second, relative reliability *r(r)*, which considers the compatibility of the object with the context, which presents previously chosen details and the general characteristics of the model. Third, a positional component of reliability exists *r(p)* that is also dependent on newly added details with respect to the previously generated model. The reliability of the final model *M* can be defined as:

$$r(M) = \min k = 1, \ldots n\ (r0, r(a)\ k, r(r)\ k, r(p)\ k)$$

Where *r0* is the reliability of the initial model and the reliability of each newly added detail is divided into its absolute, relative, and positional component. Thus, the final reliability equals the lowest reliability of its sequentially added details, but the result depends on the order in which the details are added because the reliability index can vary according to the characteristics of the models created in previous steps.

Tepavčević and Stojaković (2013) developed another method using Probability theory. They defined correction factors describing the grade of objects in the corresponding fuzzy set. Correction factors *K* characterize assessment of the probabilities to the resulting attributes: for instance, shape factor K_f, style factor K_s, and their arithmetic mean K_c. Thus the correction factors gain values between 0 and 1. Probabilities of occurrence of every detail and parameter of the object incorporate adequate correction factors. The final result is a table showing a list of probabilities of the single characteristics added in a sequence of predefined steps. The resulting visualization proves that fuzzy logic can be nicely combined with procedural modelling and CGA shape grammar.

1.4. Explaining by simulating. A new approach to Virtual Archaeology

From my point of view, Virtual Reality has made archaeological research simpler, safer and quicker. Before Virtual Reality, to understand how a prehistoric object was used in the past, one had to test the original or materially build a physical surrogate of it. This approach is more expensive, slower and limited, not to mention that, in some cases, the manipulation of the sample could let to its destruction/damage meaning that, in order to undertake more experiments, another sample was needed, which translates into the need of more time, more money etc. Virtual Reality allows us to reduce considerably these unfavourable aspects: we can create a virtual model of the object we are interest in and we can use it as a "guinea-pig". We can modify the model as we please, we can run all the tests we want, we can even destroy it without worrying about costs or to harm the sample because we will always be able to reverse the procedure turning back to the original and all of this in a fraction of the time it would have taken with the previous techniques. We move from a computer model "depicting" the monument, to a "solid modelling" analysing it (Reilly 1992).

Some examples of the potential of this alternative approach "understanding by reproducing" are the Çatalhöyük project (Turkey) (among the numerous publications: Morgan 2009; Forte *et al.* 2012, 2015; Forte 2014a; Lercari *et al.* 2017), the reconstruction of the *Igluryuaq* or Mackenzie Inuit winter house (Canada) (Levy *et al.* 2004; Dawson and Levy 2006), the project Virtual Rome (Italy) (Calori *et al*. 2009; Pescarin *et al.* 2009) and the project Alhambra Virtual (Spain) (Fuertes *et al*. 2005; Gonzáles and Martínez 2009). These experimentations with VA and VR in archaeology, that brought to light pros and cons of them, and the constant search for the "perfect tool" capable to handle all the archaeological data lead to the development of the so-called Cyber-Archeology (Forte 2011).

According to Forte, Cyber-Archaeology (henceforth CA) goes beyond a simply "reconstructive" approach, aimed at the *simulation* of the past and not on its reconstruction: the simulation is the core of the process. The first 3D models of Rome, Tenochtitlan, Beijing, and Çatalhöyük were static, photorealistic models, displayed in a screen or in a video but not interactive (Barceló 2001). Furthermore there was no interrelation with human activities or social behaviours (Forte 1997), they were wonderful empty boxes, like the virtual Pompei built in the 90s (Cameron and Kenderdine 2010). CA does not look for "the interpretation" but for achieving possible consistent interpretations and research questions: "how" is more important that "what" according to a digital hermeneutic approach (Forte 2011, 2014, 2016). In short, CA simulates the past in the present to understand their mutual relationships. For this, it is better to think about a "potential" past, "a co-evolving subject in the human evolution generated by cyber-interaction between worlds" (Forte 2010, 2011). The most important distinction between virtual and cyber archaeology is in the relation the interactive factor: data entry, feedback, simulation. The workflow of data generated by cyber-archaeology is totally digital and can make reversible the interpretation and reconstruction process: from the fieldwork to virtual realities. In short, the cyber process involves a long digital workflow, which crosses all the data in different formulations and simulations in a continuous feedback between existing information (data input), produced information (for example reconstructed models) and potential information (what is generated by simulation) (Forte 2014a-b). Examples of CA are the Virtual Museum of the Ancient Via Flaminia (Italy) (Forte 2008; Baldassarri *et al.* 2013) and the Khirbat el-Nahas Project (Jordan) (Levy *et al*. 2014).

Cyber Archaeology offers a different approach to the problem aiming to go beyond the reconstruction processes and focus in a wider, systemic simulation of the past (Forte 2014b). From this point of view the reconstruction is considered as a "false dilemma" since the reconstruction is always an approximation of the past: the real core-topic is to make transparent the full process of model creation. To achieve this goal a primary tool is represented by the collaborative environment possibilities. The importance of making transparent the reconstruction processes and the wider systemic approach results in an acceleration and simplification of the interpretative processes through collaborative environments. Even though no shared standards or technical solutions have been proposed to formalize and make the reconstruction processes part of the archaeological modeling language.

It is our view that the real value of archaeological data should come from the ability to extract useful information from them. We think that when it comes down to understand the functioning of an artefact, or part of it, Virtual Reality, Reverse Engineering and Functional Analysis are the essential tools to do so since they are, in theory, capable of providing us with information about function, properties and relations among parts of the artifact analised. Reverse Engineering allow us to understand the processes behind an artefact by simulating the artefacts function(s) and inferring possible inherent working processes (Moitinho 2012), Functional Analysis helps us to understand how the artefact worked but also how it was used (keeping in mind that there might be a difference between the original function for which an object has been created and the real use: e.g. a spoon is created to eat but I can use it to dig a hole). With these two points in mind, we can begin to investigate the form and shape of archaeological observables, in our case, the timber buildings at the La Draga archaeological site, usually hypothesized as remains of a pile dwelling. In order to do so we should analyse functionally each architectonic wooden element found at the site, trying to understand their role and how they were used in the house construction. This can be approached by reasoning backwards from a hypothetical protypical house to the preserved remains ("reverse engineering").

1.5. Functional Analysis. Looking for the purpose of the computer simulation of archaeological artifacts

Simply put, functional analysis is what we need to determine the function of an object or part thereof. In this research, functional analysis was the means to which determine the function and the role of each architectonical wooden elements or, at least, to try to.

As clearly described by Moitinho (2013), we can describe functional analysis as the analysis of the object's disposition to contribute causally to the output capacity of a complex containing system of social actions (Cummins 1975, 2000, 2002; Barceló and Moitinho 2012). Such a definition includes the use of objects used in a direct way with a material purpose (instruments) and objects used in a metaphorical way with an ideological intention (symbols). Functional analysis provides a functional explanation of any particular subject. A functional explanation involves the decomposition of a system to its parts and explaining its mechanism/working through the organization of these parts with one another. For instance, I can explain how a car works by referring to its parts and how they are placed with one another. Larry Wright (1973) gave the following analysis of function:

The function of X is Z means:

a) *X* is there because it does *Z*,

b) *Z* is a consequence (or result) of *X*'s being there.

According to Dennett (1987, 1991), the function of a certain item is determined – or should be – by what it is best able to do (or be) given its physical constitution and its context. In accordance with Bonnet (1992), a function is taken as an activity, which can be performed by an object. Therefore, we can consider that the object's activity is in fact its operating mode or behaviour specification. To Balachandran and Gero (1990) an object is defined by:

- **Function:** those properties that dictate the object's intended purpose and requirements.

- **Structure:** those properties that would represent the description of the whole and its constituents.

- **Behaviour:** those properties that would spell out how the structure of the object achieves its function.

Function properties would dictate the object's intended purpose and requirements, structure properties would represent the description of the whole and its constituents, while the behaviour properties would spell out how the structure of the object achieves its function (Moitinho and Barceló 2013; Moitinho *et al.* 2013). According to Leyton (1992), it is possible to assign different functions or actions (possible behaviours) to each part of an object. The assignment of causal interactions to features defines the object as itself. In these terms, one could say that the function of an object is the result of the actions applied to it and the actions that the object applies back to the environment (Moitinho 2013). Leyton (1992), in order to describe these concepts, used the examples of a cup:

> "*We can assign different functions or actions (possible behaviours) to each part: the flat bottom is for standing the cup on a surface; the handle is for grasping the cup when lifting; the inside is for*

> *containing the liquid; the rim is for supporting the cup against the lips when drinking. The assignment of causal interactions to features defines the object as a cup".*

According with this, an object could be described by means of five components:

1) INPUTS - *e.g.*, standing up, lifting.

2) OUTPUTS - *e.g.*, conveying liquid.

3) STATES - physical characteristics of the object, *e.g.*, its form.

4) FIRST CAUSAL RELATIONSHIP - *e.g.*, lifting (input) acts on form (state) *e.g.*, conveying liquid (output).

5) SECOND CAUSAL RELATIONSHIP - *e.g.*, lifting (input) acts on form (state) *e.g.*, form does not change (dynamics: next state).

The definition of function we are describing here works perfectly when applied to objects which have been made according to a clearly defined purpose (Wright 1973; Neander 1991; Millikan 1999). However, in many cases, the correlation form-function is not always direct or clear. An example are the objects with symbolic use. Is the definition still working? According to Wobst (1977) it is, because style too, has a function. Martin Wobst described style as:

> "[…] *that formal variability in material culture that can be related to the participation of artefacts in processes of information exchange*".

Consequently, *style* has the "function" to communicate toward the exterior particular messages, and it is the result of intentional choices: a flag with a specific pattern, for example, indicates the membership to a particular social group, and not to another (Moitinho 2013). Another example are prestige artefacts without any "practical" use, but expressing to "strangers" the wealth and power of the possessor, and thus reinforcing social bonds (Wiessner 1983, 1989; Binford 1989; Hayden 1998). This mean that a rigid boundary between style and function does not exist (Bettinger *et al*. 1996; Hurt and Rakita 2001; Brantingham 2007; Kirsch 2009).

Although functional behaviours (symbolic or non-symbolic) seem to be goal-directed activities, sometimes desirable ends are achieved through the incidental or even accidental use of an object, and consequently the use of archaeological artefacts can also be opportunistic (Barceló 2014). The way of a particular object is being used now can be different from its original purpose (St. Amant 2002; Bicici and St. Amant 2003). This was the point used by James R. Sackett to question Wobst's theory (Sacket 1985). According to Sackett there is an important difference between *"things that people do of their own free will from the things they do because they have to".* If Wobst considered functional behaviours only the things that people are constrained to do, Sackett considered behaviours also the thing that people do when unconstrained. A presumably non-functional behaviour would denote an action that does not have detectable intended purpose. The closer an action is unintended, the less likely it is to be functional, i.e., patterned by rational choice. Binford (1989) has considered this functional/non-functional dichotomy as an opposition between conscious, explicitly-rational, problem-solving behaviour, on the one hand, and unconscious, rote-learned motor habits, and socially or symbolically-motivated behaviour, on the other (Moitinho 2013). The distinction between 'functional' and 'non-functional' seems to be established between material consequences that are subject to causal intentional explanation and material consequences that are not (Dunnell 1978).

1.6. Functional Analysis through Reverse Engineering

The function of archaeological artifacts and observables can be determined using Reverse Engineering (henceforth RE) theory, techniques and technology (Barceló 2010; Moitinho 2013; Moitinho and Barceló 2013; Moshenska 2016). Theories of reverse engineering have not hitherto been employed in archaeology largely (Bouzakis *et al.* 2011), although they are used (most often implicitly) in experimental archaeology as discussed by Pierce (2005).

RE is the process of extracting missing knowledge from anything man-made, by going backwards through its development cycle and analysing its structure, function and operation (USAITA n.a.; Dennet 1991; Eilam 2005; Raja 2008; Wang 2011). In the words of Eldad Eilam (2005):

> *"Reverse engineering is the process of extracting the knowledge or design blueprints from anything manmade [sic] ... it is very similar to scientific research, in which a researcher is attempting to work out the 'blueprint' of the atom or the human mind. The difference between reverse engineering and conventional scientific research is that with reverse engineering the artefact being investigated is manmade, unlike scientific research where it is a natural phenomenon'."*

In this way, we can build Computer Aided Design models (henceforth CAD) of physical parts whose drawings are not available by digitizing an existing prototype, creating a computer model and then using it to manufacture the component (Xia 2014). One major goal of RE is not just to understand which pieces of an object are important and how they are connected, but also how the object itself and its parts works (Stowers *et al.* 2014; Eilam 2005). While conventional engineering transforms engineering concepts and models into real parts, in Reverse Engineering real parts are transformed into engineering models and concepts (Várady *et al.* 1997). Today VR experiments—complemented by advances in diverse fields such as genetics, 3D and data analysis techniques—are revealing new insights into the mechanisms by which most objects work.

Apart from the applications in mechanical engineering, RE also has applications in other engineering disciplines. In medical engineering, the successful design and fabrication of custom implants require a detailed knowledge of the surrounding bones and a good CAD model. With computer-assisted tomography (CT), it is possible to extract the bone structures in 2D contours. One can then create surface models of the bone structure for customized implant design (Bloomer 1994). The same technique of using CT-scanning and surface modelling can also be used to investigate the anatomical and morphometric differences between fossil and extant hominids for scientific research (de León and Zollikofer 1994). Reverse engineering techniques can be used to reconstruct a damaged work of art or to make a duplicate. The film and entertainment industries also use reverse engineering techniques for character modelling. One can also use reverse engineering techniques to create a virtual environment for virtual reality research. By digitizing and CAD modelling one can create mathematical descriptions of any object and thus make a rich and realistic virtual world (Ma and Kruth 1998; Moitinho and Barceló 2013). As for these areas, also in archaeology the use of RE could be multiple: for example, could be necessary to produce a copy of a part, when no original drawings or documentation is available (Barceló 2009) as in the case of the Siecha raft–a Muisca (Rueda and Escobar 2017). In other cases, we may want to re-engineer an existing part or an entire element, when analysis and modifications are required to understand functions and testing functional hypotheses, as for the study of the pottery (Kilikoglou *et al.* 1998; Tite *et al.* 2001; Kilikoglou and Vekinis 2002; Pierce 2005; Neamtu *et al.* 2012), machinery (Laroche *et al.* 2008), and even complex process like the glass production (McArthur and Vandiver 2017) or the casting technologies (Garbacz-Klempka *et al.* 2017).

In many occasions one may be faced with a situation in which a part has to be manufactured based solely on an existing prototype with no existing drawing or solid model. This would typically be the case for old and exotic parts for which, for examples, the engineering drawing no longer exists (e.g. defunct manufacturer, casting/moulding patterns) and/or parts are just hypothesized. In such cases, we have to reconstruct the part from the existing prototype by first building the virtual model and then the subsequent manufacture. This procedure of generating the model, starting from an existing part or prototype is termed reverse engineering (Puntambekar 1994).

It is possible to summarize the RE process in three main steps:

- **Digitizing the part**: the crucial part of RE is data acquisition. This is invariably the first step in the process, and a wide variety of metrological equipment can be used for this. Essentially, each method uses some mechanism or phenomenon for interacting with the surface or volume of the object of interest. There are *non-contact methods*, where light, sound or magnetic fields are used, while in others the surface is touched by using mechanical probes at the end of an arm (*tactile methods*). In each case, an appropriate analysis must be performed to determine positions of points on the object's surface from physical readings obtained. For example, in laser range finders, the time-of-flight is used to determine the distance travelled, and in image analysis the relative locations of landmarks in multiple images are related to position. Each method has strengths and weaknesses which require that the data acquisition system be carefully selected for the shape capture functionality desired.

- **Model generation:** the model can be created *ex-novo* on the base of information (e.g. books, painting, archaeological evidences etc.) or by scanning the existing object. In the second case, the data is available just as a cloud of points. Geometry has to be fitted to this point data, and this is essentially a manual process in which considerable user interaction and discretion is called for. Various methods exist for the fitting of surfaces to point data. The surface used can be either algebraic or parametric (Foley *et al.* 1990).

- **Inspection or manufacture:** the final step consists in studying the 3D digital model, in order to obtain meaningful information. It goes without saying that the quality of both captured and processed data will always constrain the reliability and usefulness of the information. The 3D digital model can be integrated by additional data (e.g. material properties, mass, kinematics and dynamics etc.). When the final model is ready is possible to run computer simulations that is manipulating virtually these enhanced multidimensional models, to simulate possible uses and behaviours of the object. The model can be used as a basis for a variety of operations such as manufacturing the object, automated dimensional inspection (Menq and Yau 1991), error analysis (Schneeberger *et al.* 1983) and tolerance analysis (Turner 1988). (Puntambekar 1994). Depending on the needs it is also possible to integrate additional data to the 3D digital model data (e.g., material properties, mass, kinematics and dynamics).

Using a full reverse engineering approach, the way we understand computer simulation in this research is parallel to Maurizio Forte's Cyber-Archaeology concept, as presented *supra*.
We are well away from standard virtual reconstruction, sometimes confused with post processing of digital acquisition (*mesh reconstruction*, like in Kazhdan *et al.* 2006), as a series of steps limited to the documentation, and visualization of "lost" archaeological contexts (for a critical approach to the terminology see Golvin, 2003, 2005 and Seville Principles, p. 3, "definitions"). When we built a model we intend there are two different procedures to create a geometric model: the inductive procedure and the deductive procedures (Barceló 2001):

- **Inductive**: is used when one has sufficient information. We can use polygons, connect points and interpolate parametric surfaces or volumetric primitives.
- **Deductive**: is used when the information, for different reasons, are scarce or not easily accessible. In this case, we can generate simulated data to simulate what is missing.

We intend a full deductive approach. Archaeological data are almost always incomplete and not only because a "piece is missing" or because an artifact is still buried, but also because we cannot see human behaviour in the past causing the materiality, size, shape, form, texture and position of such an object. Therefore, we have to "deduce" the missing data: we create a hypothetical model, we fit it to the incomplete input data, and then we use the model to simulate the non-preserved data.

1.7. A deductive approach to the prehistoric buildings computer simulation: the BIM

BIM (Building Information Module) is a process, not an application. It is based around models used for the planning, design, construction and management of building and infrastructure projects faster, more economically and with less environmental impact. These BIM models are different from CAD drawings that may be 2D or even 3D. BIM models are made up of intelligent objects that when changed stay updated throughout the design no matter who is working with it. The key word in BIM is "Information". BIM is centred on models made up of objects. Moreover, unlike 2D CAD, in which a user describes a real-world three-dimensional object with multiple 2D drawings, with BIM the user directly constructs a 3D digital model, and from this model produces 2D projections by way of description.

In the last years, both the use of the term and the process known as BIM – Building Information Models and Building Information Modelling – is increasingly growing among the archaeological literature especially if connected with the documentation on the Cultural Heritage (Calvano and Guadagnoli 2016; Calvano and Sacco 2016; Calvano and Casale 2017; Gigliarelli *et al.* 2017). However, similarly to other process and tools like GIS or CAD, BIM technologies were already in use in architecture. The earliest documented example of the concept of BIM as we know today date back to the Eastman's "Building Description System" where the BIM routines were described as:

> [Designing by] *". . . interactively defining elements . . . deriving sections, plans, isometrics or perspectives from the same description of elements . . . Any change of arrangement would have to be made only once for all future drawings to be updated. All drawings derived from the same arrangement of elements would automatically be consistent . . . any type of quantitative analysis could be coupled directly to the description . . . cost estimating or material quantities could be easily generated . . . providing a single integrated database for visual and quantitative*

> *analyses . . . automated building code checking in city hall or the architect's office. Contractors of large projects may find this representation advantageous for scheduling and materials ordering*." (Eastman 1975).

Despite his pioneering insights, the term "Building Modelling" (meaning Building Information Modelling as we intended today) appears, for the first time, in 1986 on the paper titled: "*Building Modelling: The Key to Integrated Construction CAD*" by Robert Aish (Aish 1986). In this paper, Aish set out all the arguments for what we now know as BIM and the technology to implement it, including 3D modelling, automatic drawing extraction, intelligent parametric components, relational databases, temporal phasing of construction processes and so forth. The complete wording "Building Information Model" appears for the first time in 1892 on the paper "*Modelling Multiple Views on Buildings*" by G.A. van Nederveen and F. Tolman (van Nederveen and Tolman 1992).
Even its long history, today there is not a single, widely accepted definition of BIM. In this work I intend the BIM as "*an intelligent simulation of architecture*" using the definition presented by Eastman in his "*BIM Handbook*" (Eastman *et al.* 2008). According to Eastman this simulation, in order to be functional must be:

- Digital.
- Spatial (3D).
- Measurable (quantifiable, dimension-able, and query-able).
- Comprehensive (encapsulating and communicating design intent, building performance, constructability, and include sequential and financial aspects of means and methods).
- Accessible (to the entire team through an interoperable and intuitive interface).
- Durable (usable through all phases of a facility's life).

Even if all these points are important, the BIM key stone is that, unlike other process that produce 2D objects, the ones created using BIM are parametric object. Parametric BIM objects are defined as follows:

- Consist of geometric definitions and associated data and rules.
- Geometry is integrated non-redundantly, and allows for no inconsistencies.

When an object is shown in 3D, the shape cannot be represented internally redundantly, for example as multiple 2D views. A plan and elevation of a given object must always be consistent.

- Parametric rules for objects automatically modify associated geometries when inserted into a building model or when changes are made to associated objects (for example, a door will fit automatically into a wall).
- Objects can be defined at different levels of aggregation, so we can define a wall as well as its related components. Objects can be defined and managed at any number of hierarchy levels. For example, if the weight of a wall subcomponent changes, the weight of the wall should also change.
- Objects rules can identify when a particular change violates object feasibility regarding size, manufacturability, etc.
- Objects have the ability to link to or receive, broadcast or export sets of attributes, e.g., structural materials, acoustic data, energy data, etc. to other applications and models.

The current generation of BIM architectural design tools, including Autodesk Revit® Architecture and Structure, Bentley Architecture and its associated set of products, the Graphisoft ArchiCAD® family, and Gehry Technology's Digital Project™ as well as fabrication - level BIM tools, such as Tekla Structures, SDS/2, and Structureworks all grew out of the object - based parametric modelling capabilities developed for mechanical systems design.

Obviously, when it comes down to archaeology, the BIM process, as far as the related programs, have to be adapted to the need of the discipline. Even so, the

BIM process has a huge potentiality in managing all the information about the cultural heritage. Cultural heritage documentation tasks usually involve professionals from different knowledge areas, which implies not only a huge amount of information and requirements, but also a very heterogeneous set of sources, data structures, content and formats. Using the "usual" tools, merging all these data could become very difficult, if not even impossible. The BIM could "solve" or at least "facilitate" this process and makes the fruition of the data easier, faster and complete. That is, as said before, because BIM is a process, not a program so, in order to complete the process, one could use different programs choosing among the ones more useful for the own situation. Among all the things that one could achieve using the BIM process there are:

- The digital representation of the existing building.
- An informative database about all the different elements of the heritage.
- A recurring checking of the health condition of the heritage.
- The evaluation of the effects of different typology of intervention.
- Geo localization.
- Shape of the element.
- Materials.
- Different layers of materials.
- State of decay.
- Historical information.
- Environmental conditions.

2
METHODOLOGY

"The house had a name. The Banana House. It was carved onto a piece of sandstone above the front door. It made no sense to anyone. „

HILARY MCKAY, SAFFY'S ANGEL (2001)

2.1. NEOLITHIC BUILDING DIVERSITY: TOWARDS A FUNCTIONAL ANALYSIS OF BUILT SPACE

Archaeology has been traditionally focused on the study of the great ruins of palaces and temples. Concentrating on remarkable features along the lines of V. Gordon Childe's characteristics of civilizations, large structural works were specifically sought after. However, as many other sciences, the study of archaeology has changed drastically over its history. Over time, more and more tools coming from other disciplines were assimilated allowing to widen the archaeology focus. One of the first development has been a new interest for the "small buildings", marking a shift from the extraordinary to the everyday (Steadman 1996). Houses, dumps, fields soon became the new "fashion" and archaeological studies begun to focus on domestic settings in order to better understand the day to day lives of the common citizen (Sanders 1990; Fisher 2009) laying the foundations for what will become the New Archaeology, an archaeology marked by a functionalist approach which concentrates on purpose rather than descriptive characteristics. Even with this new approach, architecture remains one of the main pillar of archaeology because, among the other things, is often a canvas for changes with a society or culture. Social, economic, or political shifts within populations materialize as modifications in the built environment. As Hillier and Hanson (1984) assert:

> *"The most far-reaching changes in the evolution of societies have usually involved or led to profound shifts in spatial form and in the relation of society to its spatial milieu; these shifts appear to be not so much a by-product of the social changes, but an intrinsic part of them and even to some extent causative of them".*

Therefore, merging established knowledge of elite, political, and religious spheres of society, provided from anthropology and ethnology, with the examination and study of private household buildings, supplies archaeologists with a more versatile, well-rounded perspective towards ancient civilizations. This renewed settlement archaeology investigates communities on a landscape-wide scale and places emphasis on spatial patterns and symbolic arrangement of settlements (Ellis 2000) raising the need to determine what is the built space (or built environment) and what the concept of built space meant compared with the natural space. However, the definition, as Rapoport (Rapoport 1970) and others underlined, it is not simple nor unitary. Above all the possibilities, and according to what stated by Rapoport (1977), the most basic distinction is "between human and non-human space" between "natural" and "cultural or built" space, where natural identifies the environment untouched, in any manner, by the human action, and cultural all those environmental areas "touched", in any way, by the human action. This clarification is very important since the absence of tangible human activities is not enough to exclude an area from the built space (Bradley 2000; Fontijn 2007): as Rapoport specified, inside the behavioural/action space there could be areas, like sacred ones, that could be rest untouched by the human direct activity (Brown and Moore 1971). Therefore, using the words of Lawrence and Low (1990), we can consider the build space "*as formed by of all built forms – both structures and unstructured spaces created by human activity*". It is clear that the differences between natural and cultural environment are blurred and difficult to find (Arnoldussen 2007).

When it comes down to studying those parts of the built space that were actively used by the human groups, the archaeologists relay, among other things, on the tools developed by the architectonic sciences. These tools has been adopted and adapted to the needs of the archaeology and the term architecture itself, when used in archaeology has changed in time:

> "*The term architecture is defined in new ways by integrating it into anthropological dimensions, including primatological and paleanthropological considerations. Thus the term 'architecture' implies: all what humans and their biological relatives built and build"* (Egenter 2006).

Therefore, archaeology use or have to use not only the "simple" architectural tools, but also those tools provided by the architectural anthropology (Birx 2006). Architectural anthropology is closely related to Otto F. Bollnow's (2011; 1961) anthropology of space. His theory states that cultural, or human space (built space), is closely related to the evolution of human dwelling and settlement, in opposition to the homogeneous concept of universal space idea developed during the 14th century (Bollnow 1963). This implies that the human perception of the space and the space conception were originally formed in small, local settlement units, in which architecture provides the semantic systems for spatial organization and that we have to assume a long extension process of spatial perception and conception (Egenter 2006). Therefore, the first step in understanding the ancient human communities should be to understand the settlement and its basic unit, the house. A settlement, as defined by Brück (1999), is part of the built space, it is a location where every day (domestic) activities such as sleeping and cooking occur. Usually, the presence of a house implies the presence of a settlement (Arnoldussen 2007). In this sense the house could be considered as the basic unit of the built space. As Rapoport said:

> "*Home, in the first place, is an institution, not a structure for complex matters. For cultural matters, it is under the influence of culture. Even at first, the concept of home has not been a totally functional space. The positive point of creating an ideal environment for the family as a social environment points to home as shelter, but the important thing is that this makes sheltering as an obligation for this social institution. From the first day, man created his home because of his beliefs in rituals and cultural issues*" (Rapoport 1969).

So, resuming what has been said, to understand a complex system this has to be decomposed to identify, where possible, all its components until the basic ones. In our case, the complex system is the built space and the basic elements are the buildings and, more specifically, the house. These buildings should be investigated starting from the point of view of architecture and then through the lens of the other sciences extending, little by little, the focus of the research to the areas around and between buildings spaces that often are of critical social importance in a society (Robin and Rothschild 2002).

The cornerstone of such kind of investigation is, as said before, the study of the connection between the built environment and human behaviour. Amos Rapoport is one of the most prominent scientists studying these connections (Rapoport 1990). His research has culminated in 'environment-behaviour studies' (EBS) which is now a leading feature of archaeological architectural thought (Steadman 1996). Both the theories of settlement archaeology and human behaviour are "children" of the New Archaeology functionalist approach. This new way of doing archaeology involved newer processual practices that used scientific methods, instead of historical ones as in the case of settlement archaeology. In other cases, like EBS, post-processualist movement worked as starting assimilating, little by little, social and cultural ideas as well (Vila *et al.* 2003). One of the results of these new perspectives of investigation has been the development of the "household archaeology", the merging of settlement archaeology and 'activity area research' (Steadman 1996). This new discipline approach the household not only as an aggregate of architectonical remains, but as the basic socioeconomic unit, focusing on the house, and the artifacts found within it, as a reflection of the social and economic structure of the culture or community (Drennan 2010). The new spatial analyses used in settlement archaeology were adopted for more microscale examination of material remains and material remains, their spacing, and knowledge of the culture began to be used to determine what activities were being performed, where, and by whom.

Tightly connected with the household archaeology is the development of the ethnoarchaeology. If the first one centres its focus on economic aspects, ethnoarchaeology main goal is to find "the nature of social relations within the domestic unit and other hidden symbolic elements" (Steadman 1996), using methods similar to those used by the household archaeology.

These new disciplines, with their new socio-economic focus, changed the way the archaeologists perceive and study the structures. The new scientific approach looked at how these economic factors shaped the house, the activities that took place there, and changes over time. Richard Wilk (1989a, b) and Richard Blanton (1994) were among the first ones to develop these innovating ideas (Steadman 1996). Hillier and Hanson (1984) used the new theories in order to shape forms of spatial analysis tailored specifically for architecture on a settlement and individually-based level, centring on inter- and intra-structure relationships of space. Their aim was, in most general sense, to understand what caused variation and similarity in architectural structure why, even within a small region, one with little deviation in climate, topography and/or technology, creates great variations in architectural and spatial forms and, on the other hand, why analogous forms could be found across large expanses of time and space. Before their studies, these phenomena were explained as result of the human treatment of territory, as a product of the need of the groups to claim a territory as their own. From this point of view the space only has ‘social significance’ if it is connected to a certain group. By contrast, Hillier and Hanson (1984) developed the theory that differences in form could not be explained by a ‘constant rule’ of territory behaviour and that architecture cannot be defined just as result of outside cause. The ordering of space by humans is social behaviour, “*a form of order…which is created for social purposes*”. They concluded that in order to achieve a theory of space, it must be explained in its own terms, what they call ‘descriptive autonomy.’ To explain their theory they resort to two peculiar examples: the game of hide and seek and the set-up of an army camp. In the first case all the participants playing knowing the rules of the game and understands the qualities to look for in a hiding space, they have a “model” of the game in their minds and this model is like a genotype, the set rules that define possible outcomes. Therefore, even if the rules and then the model are the same, each time the participants play the game in a new location the outcome is different, the game looks unique, or is carried out differently. Each specific game would parallel the concept of a phenotype. In the second case, the army camp, they demonstrate the same idea except it includes the naming of different entities. The formation of the tents and the structures change in changing the landscape. Yet, the relationships between specifically identified entities stays the same because these are spatial connections that must be acknowledged and adhered to whenever the camp is established. Moreover, the army camp example introduces the idea of the universal term, category, and ‘transpatiality.’ The ‘specific identities’ in the army camp example can also be understood as a universal term, because they are a class of objects that are identified as being similar to one another disregarding their location: the general’s tent can be located and identified in any camp thanks to its placement in regard to other entities. This identification is a category, which is made possible by transpatial integration, “the summation of objects into composite entities without regard for spatio-temporal indicability or location” (Hillier and Hanson 1984). They use these examples to assert that the model mapped in the brain is knowable, as described by the syntax model. Describing the model through language or mathematics gets you to the syntax and the underlying principles that dictate spatial life.

However, to be functional a syntax model must achieve four things:

1) Find the objects that cannot be further reduced, also known as ‘elementary structures’.

2) Represent these structures as notation to avoid wordy verbal explanations.

3) Demonstrate how the structures relate to one another to make a system.

4) Illustrate how they are combined to create complex structures.

Vischer (2008) propose a user-centred theory of the built environment. This theory is built around the concepts of the building user’s experience and the user–environment relationship (Koskela 2008). The way to analyse, understand and evaluate ways in which the building supports the user’s activities is to explore systematically and in detail the user’s experience. This is a complex and difficult task. The user–environment relation is dynamic, interactive and reciprocal: part of the user’s environmental experience includes the consequences of any user behaviour that may occur. Another part of the theory is how the data on the user experience are assessed. In essence, if users indicate that environmental features or conditions are supporting peoples and what they are doing, the built environment is effective and functional. This applies to the three units of user: individual, group and organization.
Moffatt and Kohler’s (2008), on the other hand, argue that the built environment can only be defined in contrast to the ‘un-built’ environment, the ecosphere, and that the relation of the built environment and the ecosystem is constantly changing. In their work, they state that only in the last decade the relationship between the built environments, the society and the ecosphere have emerged and they analyse four themes present in these developments. First, there is a trend towards extending system limits in time and space, as exemplified by the method of life cycle analysis. Second, a balanced system perspective is emphasized: the target is to achieve a balanced, sustainable relationship between the natural and

the built. The method of mass flow accounting is used for this purpose. Third, a shared framework for representing the built environment is required, for coping with the associated complexity. Fourth, a scalable perspective is needed to model the net effects of various flows for stocks and urban systems. In this respect, combining flow-based approaches for stocks and capital-based approaches has turned out to be advantageous. Moreover, the authors explore new concepts of time for the built environment, such as ecological time. From this viewpoint, long-term ecological modelling provides new insights for designing complex systems, buildings and urban systems included. In their conclusion, the authors anticipate a fundamental change in design practice towards the rationale of preserving capital over time while satisfying fixed constraints.

According Rabeneck (2008), uncertainties about the product (what to build?) and the process (how to build?) arise from conflicts between two intrinsic frameworks in construction: one framework, which governs the building process, being inherited from the past, and the other, related to how buildings are thought about, constantly evolving. By constructing a purpose-made theoretical scheme for capturing the conceptual nature of the built environment, he proposes a transactional framework of building activity in terms of demand and supply, moderated by regulation. The underlying idea is that knowledge should be generated about these three components, and the relationships between them. Here the notion of performance is also introduced to elaborate these three components: desired performance, regulated performance and deliverable performance. The author contrasts empiricism with instrumentalism as scientific approaches, and suggests the latter as the suitable methodology in the context of his scheme. He also presents a programme for applied research, structured around the three components mentioned.

Cairns (2008) face the problem from a very different point of view: his starting point is the question of whether or not a unified theory of the built environment is possible. He rejects the idea of a unified theory, but likewise the notion that there should be a choice between different, possibly incommensurate theories. Instead, Cairns suggests an approach that endeavours to enable all relevant and applicable theories and concepts to be brought to bear on the problems of the built environment, as well as to confront the possibility that they might be applied selectively by powerful actors in achieving a particular outcome. The approach advocated draws upon recent interpretations of Aristotle's concept of *phronesis*, or practical wisdom. The possibilities and limitations of this approach are illustrated by referring to the research area of the workplace. It is pinpointed that different groups present different responses to both physical and organizational factors of the workplace and that those responses vary over time. This suggests that there is no simple cause-and-effect relationship between the elements of social, physical and organizational environments of work. Cairns concludes by discussing the application of such a *phronetic* approach to built environment research.

2.2. ETHNOARCHAEOLOGY AND ARCHAEOLOGY

We can say that at the core of archaeology is the attempt to understand the relationships between people and things. Archaeologists are faced with the daunting task of making sense of the variability they find in the archaeological record, which is no easy task (Skibo 2009). Aspect as the perishability of the materials used, the absence of written records, the absence of direct information about social and cultural aspect of the "everyday life" made the task even more difficult. For this reason, archaeologists have made frequent use of ethnographic data and observations to assist with the interpretation of traces of ancient human groups' settlements and activities. The information provided by ethnoarchaeology can be used to generate explanatory hypotheses for specific items or patterns recovered archaeologically, i.e., to answer the questions as: what was this? What was it used for? As applied to an artifact or artifact class, a fragmentary architectural form or a class of architectural features or to an associational pattern (Gould and Watson 1982).

There has been a long history of using ethnographic data and comparisons in archaeology, and their incorporation into archaeological interpretation was fundamental both to the establishment of archaeology as an academic discipline and the rise of a new disciplinary subfield known as ‘Ethnoarchaeology’ (Orme 1973; Lane 2014).

Ethnoarchaeology has thus become one of several research strategies that archaeologists can employ to enhance:

> *“Understanding of the relationships of material culture to culture as a whole, both in the living context and as it enters the archaeological record, and to exploiting such understandings in order to inform archaeological concepts and to improve interpretation* (David and Kramer 2001)*”.*

Although J. W. Fewkes first coined the term “Ethnoarchaeology” in 1900, the growth of a theoretically self-conscious body of literature based upon ethnoarchaeological observations has occurred only within the last 25 years or so (Gould and Watson 1982). As a matter of fact, the first comprehensive review of the aims and methodology of ethnoarchaeology did not appear until the late 1970s. At that time, Stiles (1977) provided a broad definition of ethnoarchaeology as a subdiscipline of anthropology:

> *“... Encompassing all theoretical and methodological aspects of comparing ethnographic and archaeological data, including the use of ethnographic analogy and archaeological ethnography.”*

For Stiles, the most explicit goal of ethnoarchaeology was to improve the quality of ethnographic information, so that the collected information would be more useful for archaeologists in highlighting ethnographic analogies, model building, and hypothesis testing. Researchers such as Lewis Binford in his work among the Nunamiut (1978a, 1991) and Ian Hodder’s work in Africa (1982) championed this modern approach to ethnoarchaeology. Other studies of such type also took place in Mesoamerica (Thompson 1958; Nelson 1981; Reina and Hill 1978), Australia (Gould 1971, 1978, 1980), Africa (David 1971, 1972; David and Hennig 1972; Yellen 1977), the Near East (Hole 1978; Horne 1988; Kramer 2014; Ochsenschlager 1974; Watson 1979b), the Arctic (Binford 1978b;

Oswalt and Vanstone 1967; Oswalt 1974), and the U.S. Southwest (Stanislawski 1969, 1977, 1978).

Of course, over the years, different theories and definitions of ethnoarchaeology have been elaborated. Amongst them, I consider the definition conceived by Lane to be one of the most clear. Lane (2014) defines modern ethnoarchaeology as:

> *"The study of contemporary societies, their material culture and the material consequences of their behaviour for the purposes of formulating and strengthening analogies for use in the interpretation of archaeological evidence".*

The process used in order to get and elaborate such information is called "*general comparative method*" that relies, indeed, on the use of analogies (Wedel 1938). The use of analogy is a form of inductive reasoning, a cornerstone of archaeological interpretation (Shelley 1999; Wylie 1985). In ethnoarchaeology, the two things being compared are called analogs. Analogs are comprised of a known ethnographic source and an unknown archaeological subject. Analogies are based on the premise that if the two things are alike in some aspects, then they will be alike in others. Furthermore, it implies that dissimilarities are also present. In comparing two complex models, like modern and prehistoric villages, similar attributes are considered positive analogies, dissimilar attributes are negative analogies and indeterminate attributes are neutral analogies (Deal 2017).

2.2.1. Specific Historical Analogy And General Comparative Analogy

As we said, analogy is one of the pillar of the ethnographical studies. Analogical reasoning has been discussed extensively in the archaeological literature (e.g., Anderson 1969; L. R. Binford 1967, 1968, 1972; S. R. Binford 1968; Chang 1967; Charlton 1981; Clark 1968; Crawford 1982; Freeman 1968; Gould and

Watson 1982; Green 1973; Lange 1980; Munson 1969; Murray and Walker 1988; Simms 1992; Stahl 1993; Wobst 1978; Wylie 1982, 1985, 1988, 1989).

An analogy is a form of reasoning that produces an inference about an unknown and invisible property of a subject phenomenon. The unknown property is inferred because it is observable among source phenomena that are visibly similar in at least some respects to the subject. The source is the known side of the analogy and comprises the analog; the subject is the side of the analogy that includes the unknown property (Lyman and O'brien 2001). Analogical reasoning has been commonplace in Americanist archaeology since at least the early nineteenth century (Baerreis 1961; Charlton 1981; Trigger 1989). Willey (1953) identified two distinct kinds of archaeological analogy: specific historical analogy and general comparative analogy.

Wedel (1938) is widely acknowledged as having coined the term "direct historical approach" (later renamed by Willey as specific historical analogy) in reference to a field methodology developed in the American Southwest during the 1930s, involving the excavation of documented historic sites in order to link their material culture to prehistoric sites in the same area. Other researchers (e.g. Heizer 1941; Steward 1942) quickly adopted the term.

The direct historical approach follows specific historical analogy, and assumes cultural continuity, with or without major interruption. The direct historical approach had three distinct uses:

1) It was used to identify ethnic affiliations of archaeological cultures. This was accomplished by comparing trait lists of historic, ethnographically documented cultures with those of unknown archaeological cultures (Lyman and O'Brien 2001).

2) It was used as a chronometer, before the advent of radiocarbon dating, through tracking overlapping cultural traits from known historic to unknown archaeological cultures.

3) It was used as a source of ethnographic analogs for interpreting past cultural behaviour.

Lyman and O'Brien (2001) suggest that this approach had three inherent problems. First, analogies became less effective the further back in time they were projected. Second, only cultural traits that were both specifically and structurally similar could be considered historically related, and conversely, those with superficial similarity could not. Lastly, it was recognized that not all traits evolved at an equal and constant rate.

The problems with using specific historical analogy in the reconstruction of past cultural behaviour led to the theorization of the so-called "general comparative analogy". As stated by Willey (1953), in general comparative analogy:

> *"We are interested in cultures for comparisons, in cultures of the same general level of technological development, perhaps existing under similar environmental situations".*

The difference between specific historical analogy and general comparative analogy was striking:

> *"In the general comparative analogy the artifact–behaviour correlation derives from a pattern of repeated occurrences in a large number of cultures. In contrast, the specific historical type [of analogy] depends upon the existence of a direct continuity in a single culture or area*" (Thompsonm 1958).

In a later and more detailed discussion of the two kinds of ethnographic analogy, Ascher (1961) came down decidedly in favour of general comparative analogy because it required no demonstration of heritable continuity between source and subject. As illustrate by Green (1973):

> *"General comparative analogy allows that a prehistoric culture may be compared with a contemporary one even though the two are not within the same cultural tradition [or line of heritable continuity]. However, the two groups should be at the same level of subsistence and live in comparable, although not necessarily identical, environments".*

General comparative analogies are usually believed to be strongest when taken from situations as similar to the archaeological one under interpretation as possible. However, as in the matter of prior probability with respect to direct historical analogies, this is not at all a straightforward issue (Ascher 1961). For any specific case, much depends upon the nature and extent of the alleged contextual similarities.

The general conclusion must be that all such analogies are more or less plausible models or hypotheses. Their confirmation or disconfirmation depends on their being tested by use of the archaeological record being investigated. In fact, a case can be made that one must be especially cautious of direct historical analogies because the temptation is so great to accept the contemporary populations as living prehistoric peoples in every mode of their behaviours (Watson 1979a).

2.2.2. Implementing The Theory

I set up my research following the principles of general comparative analogy. I used ethnoarchaeology and analogy to formulate viable hypothesis about forms and functions of the architectonical wooden elements composing the ancient pile dwelling of La Draga, as well as to define a viable overall structure of the house.

The first step has been collecting data about those Neolithic houses that were not pile dwellings. The data has been use both to display the huge variability in terms of house forms during the Neolithic and to eliminate those forms that did not fit the archaeological data in our possess. In fact, because the archaeological data related to the houses of La Draga were partial, we had to verify if the evidences could be indeed related to a pile dwelling and not to another typology of house.

If we used just pile dwelling houses as first and unique means for the analogies, we would be taking the risk of influencing the research from the very beginning since we would taking for granted that the archaeological remains could not be anything else. The results of this “broad” approach revealed that indeed the archaeological evidences were compatible just with a pile dwelling structure.

The following step has been recollecting as much as possible examples of Neolithic pile dwellings (those in which the structures have been described), including information from archaeological sites far away from our (e.g. China).

This operation has allowed having both a broader view in pile dwelling construction techniques and forms, both to undertake analogies also with these distant sites, following the principle that "[…] *a prehistoric culture may be compared with a contemporary one even though the two are not within the same cultural tradition* […]" (Green 1973). This new approach has increased the number of possible analogies and, therefore, the percentage of viability of the final hypothesis.

In fact, doing analogies only with the nearest pile dwelling sites just for a reason of "proximity" or "similarities in the background", would have meant narrowing the possibilities too soon, influencing the results. This selection "*a priori*" puts aside other possible analogies and prevents further discovery and/or insights.

Finally, in order to make the reconstruction the more plausible possible I decided to take into account also modern pile dwellings, including both those structures belonging to less technologically developed societies, that are still using forms and techniques of their past, and those pile dwellings belonging to more technologically developed societies. Ethnographical analogy was essential to compare these data with the data from La Draga.

As final step, I used the gathered data to understand whether there are any "universal laws" or "universal forms" in pile dwelling construction, which could "simplify" the reconstructive process.

Once I had this huge *corpus* of data reunited, I have been able to begin using analogy to compare the archaeological data from La Draga with the other pile dwellings, trying to understand forms and functions of the different house elements and, then, the overall house form. The following example illustrates the process. Among the architectonical wooden elements identified at La Draga, archaeologists found an assemblage made of crossed elements that seemed to be connected to one of the vertical forks inserted into the soil. The hypothesis was that this assemblage (as explained in detail in chapter 4.1) was part of the base plane meant to hold the floor and the entire house.

In order to verify this hypothesis I first compared the archaeological data from La Draga with those coming from other Neolithic pile dwellings settlements. This comparison seemed to indicate that our theory was correct: the other sites showed the same type of structure and it was used with the same purpose.

However I wanted to increase the percentage of reliability of our hypothesis (since the archaeological data are often partial). In order to do so I used ethnographical analogy, to compare our data and hypothesis with modern pile dwellings coming from less industrialized societies that are still using ancient building techniques. The results shown that the base plane exists also in these modern houses and has the same basic forms and functions of the ancient ones, including the base plane hypothesize for La Draga. The final step was to compare this results with modern structure of industrialize country. Astonishing enough I discovered that, even if the materials can change, the structure forming the base plane still exists and maintains, generally, the same forms and functions of the ancient one.

Therefore, we can postulate that: if the base planes from both Neolithic and modern pile dwellings share the same forms and functions, and since the archaeological evidences from La Draga seems to point in this direction too, hence we can assume that also the base plane of this site should share the same forms and functions.

This whole process not only indicates that my hypothesis was on the right path but also that such a structure is fundamental in pile dwelling buildings and it is, as I said above, an “universal forms” when it comes down to pile dwellings. The process described here, has been undertaken for all the house components.

In chapter 4 the results of this extensive analogical process are set out.

2.3. SOME EXAMPLE OF NEOLITHIC HOUSE ARCHITECTURE AROUND THE GLOBE

This chapter has been designed not only to illustrate the similarities among pile dwellings but also to describe the huge variety of Neolithic houses around the world in order to demonstrate that function defines forms and a same object can have different forms in different location, also applies to houses. This principle explains why not all the houses were pile dwellings or stone houses or wooden houses. We used just the following examples of houses, and only these, because the key of this chapter is not doing the "history of everything" but to illustrate the variability of shapes and dimensions of the dwellings as well as the different materials and techniques of construction of Neolithic dwellings. We do not intend here to analyse the causes of the dwelling variability, but remarked the diversity of solutions.

2.3.1. Iberian Peninsula

The first farming societies of Iberian Peninsula built their dwellings using a diversity of techniques and materials: earth, wood and stone are well documented among them. Although caves are used as dwelling, shelters, places of storing or burials, the first farmers also built their settlements in new open air spaces. Several examples in this open air settlement show the high variability of buildings and constructive techniques.The houses were composed by a part excavated into the soil and a superstructure, acting like roof and walls, made of organic material like wood, mud or other vegetal fibres. It is for this reason that today traces of Neolithic house are very rare and when present are almost limited to the excavated parts. At the Early Neolithic open air settlement of Plansallosa (Tortellà, Catalonia, Spain) (Bosch *et al.* 1998; 1999) the house (E1) was unicellular, slightly circular and oriented North-South. The dimensions of the construction were small, only 2.10 m long and 1.70 m large according the remains of the walls (Bosch *et al.* 1998). The base of the walls was 150 cm width and at its maximum, 60 cm high. They walls were made of river pebbles of different dimensions (from 30 to 50 cm) laying in overlapped rows, the larger pebbles laying on the outer perimeter of the structure. The base enclose a small space of 6 m^2 with entrance on the southwestern side. On the east side of the wall there are two structure, always made of pebbles, meant to hold the roofing. The walls were probably made of logs vertically placed, as their mark on the side of the base seems to suggest (Bosch *et al.* 1999).

Another good example of early farming building is preserved at the site of Barranc d'en Fabra (4900-4650 BC; Amposta, Spain) (Argilagós *et al.* 1995). It was an open-air settlement, enclosed by a circular defensive wall (of which only the stone base survive). Nine elliptical structures has been identified as houses. All these structure has similar dimensions (6 x 4 m). The walls, made of stone, were built without the use of any kinf of foundation. A vertical wooden pile, set along the major axis, held the roofing system, probably made of wood and/or other organic plant material.

One of the most important Middle-Late Neolithic site in Catalonia (Spain) is the site of Bòbila Madurell (4250-2490 BC) (Sant Quirze del Vallès, Barcelona) (Colliga *et al.* 1988; Barrasetas 1994; Masvidal Fernández and Moral Torcal 1999; Figueroa 2016). The so-called "house C11" (2600 -2500 BC) has an irregular oval form covering an area of c. 50 m^2. Its maximum length, on the N-S axis, is of c. 6.3 m while its maximum width it is about 5.4 m enclosing an area of 30 m^2. The basement was excavated into the soil, characteristic of the open hair dwelling in the Vallès and in other areas of the Iberian Peninsula y South France (González-Marcén, Martin *et al.* 1999) during the recent prehistory and until the Iron Age. The perimeter of the house is delimited by a discontinuous alignment of stones that, probably, formed part of the exterior wall. Inside the house has been identified four fireplace, a maintenance pit and the two postholes. Inside the house, other different alignments of stones probably indicate a division of the house space. On the west side of the perimeter, two large stones seems to indicate the entrance of the house. The two postholes, located on the opposite extremities of the east wall, were part of the covering system and suggest that, probably, the roof was held by wooden piles and made of organic material that left no traces. Ca n'Isach (4600-2700 BC; Fig.3) (Catalonia, Spain) is the only Middle-late Neolithic settlement completely excavated in Catalonia (Tarrús *et al.* 2016). Here, several evidences of houses of Early Middle Neolithic, Middle Neolithic peak and Late Neolithic have been found. The settlement occupied an area of 800 m^2 (Tarrús 2010). The early Middle Neolithic construction (4600-3900 BC in Catalonia) corresponds to a house with rectangular plan (building EH-7) delimited from trench in which the piles forming the house's walls were driven. In the interior of the house a structure, probably a brazier, was obtained excavating the natural rock soil. The full Middle Neolithic construction (3900-3400 BC) corresponds to four U shape houses d (EH-2 a 3 y EH-5 a 6) and the "first version" of a huge oval house (EH-1). The archaeological evidences (walls stone bases and postholes) suggest that the walls were made of stones, and wooden posts in the interior of the houses were meant to hold the roofing stystem, made of wood and/or other organic plant material. The Late Neolithic construction (3400-2700 BC) is the "final version" of the huge oval house, resembling the ovals houses with narrow entrance of the Fontbuisse group (Languedoc oriental) (Gasco 1976). In addition, in this case the houses were made of stone walls and wooden posts holding the roofing system.

In other parts of the Iberia Peninsula, other good examples of Neolithic constructions have been documented. At Fuente de Isso (c. 5000-2800 BC; Hellín, Albacete, Spain) a house basement has been found (structure 3.2) (Atiénzar *et al.* 2006). It was rectangular with the shorts sides apsidal. The walls were made of stones. The first flooring was made of pressed earth. Inside the house there was, probably a fireplace and different pits utilized as small house silos.

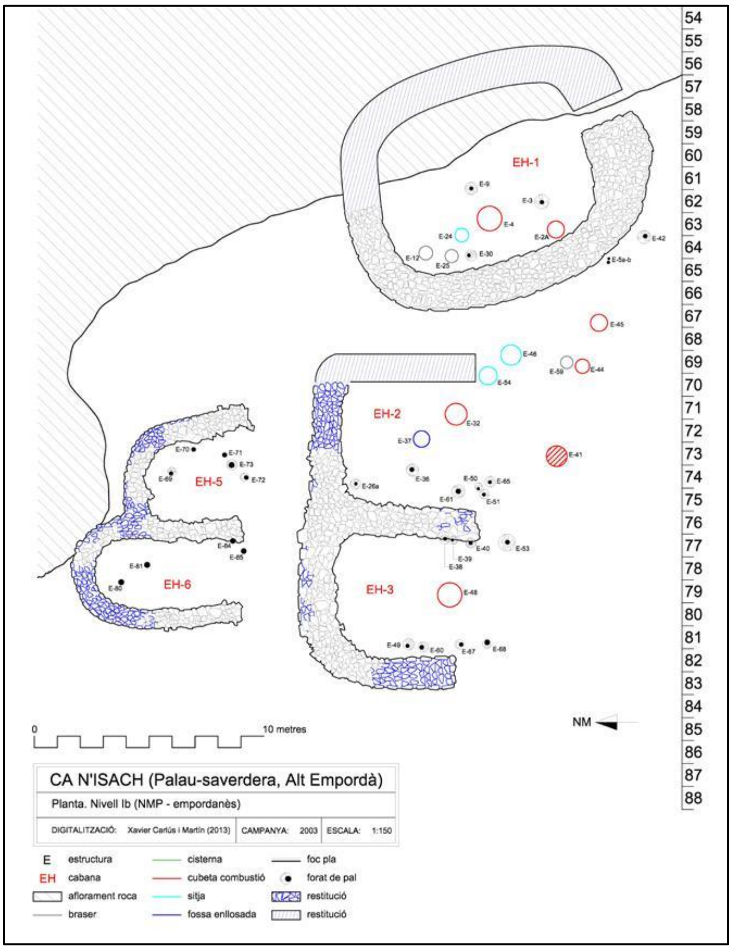


Fig.3: Ca n'Isach: houses and structures (posts holes, fireplaces, silos and tank), level Ib (Tarrús *et al.* 2016).

The walls were probably made of stone blocks, like the base of the defensive wall, or of a mix of stones and clay. Some postholes (with rests of carbonized wood) aligned along the main axis seems to suggest that wooden posts held the roofing. Even if the open-air settlement with pit dwelling is a very diffuse way of settle in the Iberian Peninsula, at Castelo Belinho (4500 BC; Portimão Algarve, Portugal) (Gomes 2013) at least five rectangular longhouses constructed with wooden posts have been identified. The best preserved house was 16 m long and 2.90 m wide (Fig.4). Three parallel lines of postholes cut into the bedrock and approximately 1.60 m apart were identified. Some still preserving the stone wedges and earth packing, helping the fixation of the vertical posts corresponds to a latent structure of a long house. The wooden piles were meant to support the walls and the gable roof, probably thatched with straw or other organic plant materials. A small wall made of stone and clay reinforced the house, on the northeast corner. The plan was oriented west east and its entrance was on its south side. A fireplace was set inside the house, in a small ground depression. In the central area a cobbled floor has been found.

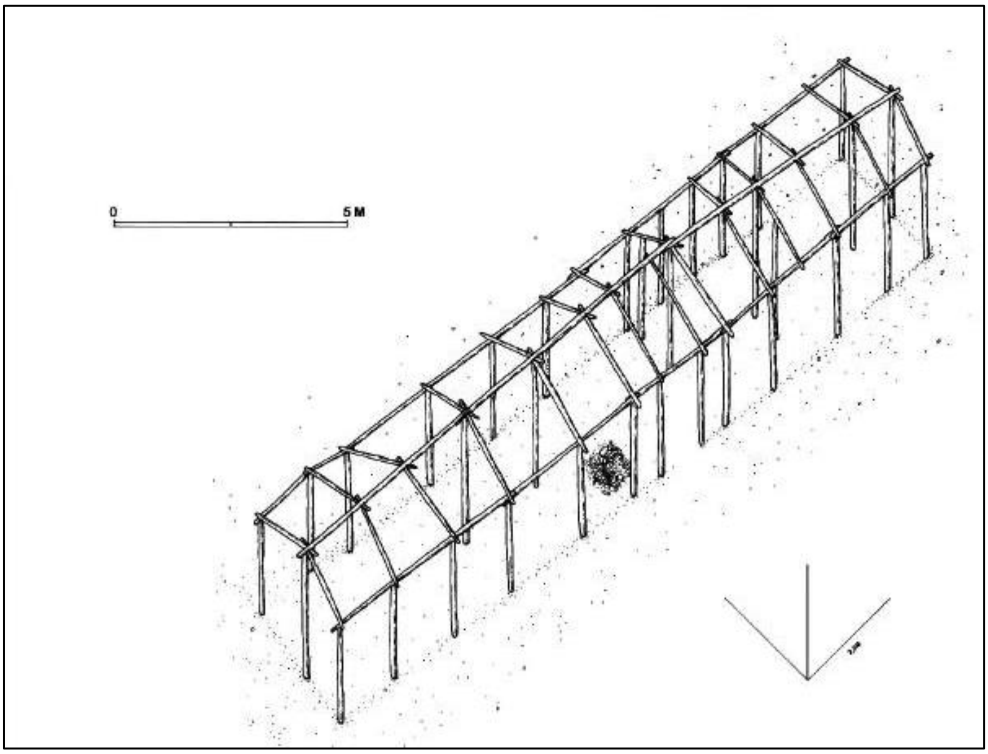


Fig.4: Reconstitution of the long house at Castelo Belinho (drawing by J. Gonçalves, after M. V. Gomes 2013).

2.3.2. The Central Europe Longhouse

Among the different house types present in the Central and Western Europe, the Longhouse seems to be the most diffuse and common. This type of house was typical of the Linearbandkeramik (LBK) culture (c. 5500-4900 BC). This culture, probably developed in western Hungary or eastern Austria between 5600 and 5500 BC (Bánffy 2004; Bánffy and Oross 2010) and spread across a vast area of Europe, from the Ukraine and Moldavia in the east, to the Paris Basin in the west, and from south of the Danube well into the northern European Plain (Modderman 1988; Whittle 1996, 2003, 2009; Jeunesse 1997; Coudart 1998; Gronenborn

1999; Bánffy 2000, 2005; Sommer 2001). Longhouses are found in settlements of various sizes and durations, from single farmsteads to large multi-phase sites, which saw several centuries of occupation (Modderman 1988; Whittle 1996, 2003; Coudart 1998; Gronenborn 1999). Generally, the longhouses were rectangular and (there are variation but the house plan is usually longer than wider) with large wooden posts dividing the interior and with external wall trenches. Floors are virtually never preserved while the walls used to be made of wattle and daub that, in some cases, seems to have trace of paint. Generally, the Longhouses are divided into two groups: the houses belonging to the earliest phase of the Linearbandkeramik culture (5600-5300 BC) generally did not exceed 25 m in length. The houses belonging to the middle and late phase 5300-4900 BC. with an average length of 20 m but there are cases of houses of 5 m or even 50 m of length (Fig.5).

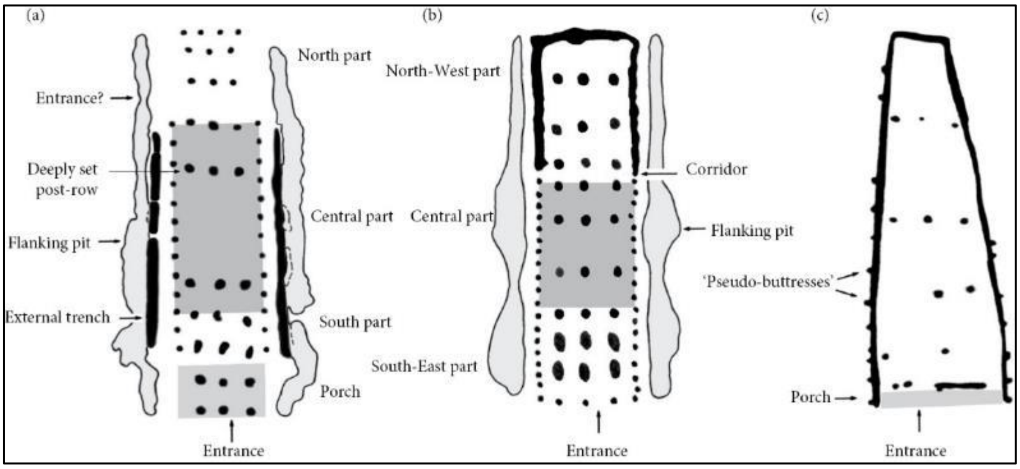


Fig.5: Representative house-plans: (a) early LBK (after Stäuble and Lüning 1999); (b) middle/ late LBK (after Lüning 2000); (c) MN (Rössen; after Coudart 1998). Not to scale.

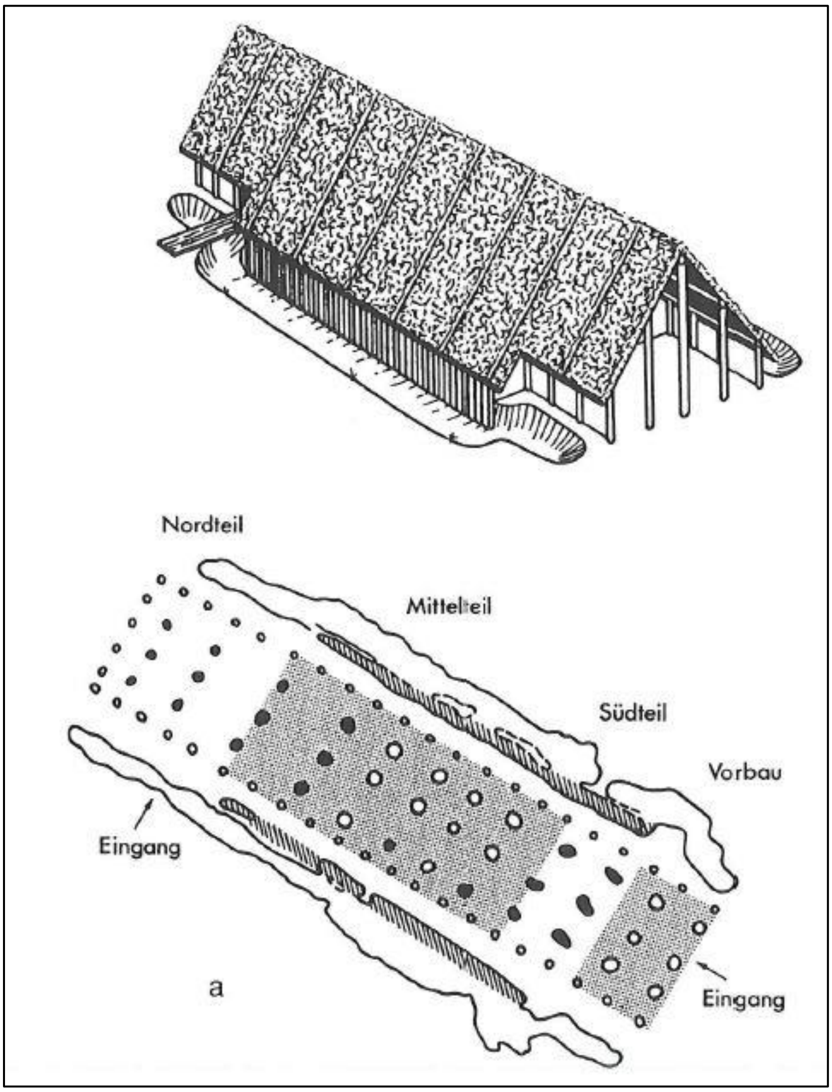


Fig.6: Early LBK house plan and its reconstruction (Stäuble and Lüning 1999).

The houses of the first group are usually more uniform that those of the second one, with rectangular plan and in the interior the posts were arranged into regular transverse rows of three (called *Dreierpfostenreihe* in German – 'three-post row' (Hofmann 2013) and had a large post-free spaces at the centre of the house (Fig.6). At the outside of the houses wall trenches may have functioned as additional roof supports or held a second set of walls. The houses of middle and late phase had more varied in shapes, varying from the rectangular to trapezoidal, sizes and with a larger number of internal posts. In addition to that, there are regional shifts in structures and arrangement of the centre posts. Over time, in many regions, houses became increasingly trapezoidal, the distances between posts increased, and small roofed porches open to the outside were often added to southeastern ends (*e.g.* Modderman 1970). The House III at Hrdlovka (4900-4600 BC chronological position with respect to the transitional Linear Pottery Culture/Stroked Pottery Culture (LBK IV/SBK I) period), Czech Republic was, 47.5 m long and had slightly trapezoidal plan (the width varies from 8.6 to 9.5 m) (Beneš *et al.* 2014). Due to this dimensions, it is considered one of the longest in the Czech Republic. Its inner structure of the postholes is relatively regular, consisting of three rows of bearing posts. The diameter of the wooden piles vary between 40 and 45 cm. The wall posts of the house ground plan show diameters of 15–20 cm, while the bearing posts in the middle part remained extremely strong. A huge trench, rectangular and oriented as the rest of the structure, limited the northern part of the house.

At the Neolithic (3000-2500 BC) site of Zeewijk (the Netherlands) archaeologists found different structure identifiable as houses (Van Heeringen and Theunissen 2001; Theunissen *et al.* 2014). Amongst them, the better preserved is the so-called Zeewijk-East structure (Fig. 7-8). This trapezoidal structure measures 22 x 5.5 – 7 m and it bows slightly outwards nearer the wider end to a width of 7.5 m. The structure is orientated NE-SW along its axial line. The construction is symmetrical and uniform in many of its components. The central post line consists of five postholes 30-80 cm in diameter, and the terminals form part of the external end walls. The northeaster terminus forms part of an entrance. Two postholes of 10-20 cm of diameter are located marginally outside the structure, yet within the opening of this entrance and they could have served as structure for a door or a temporary blocking panel. The front façade is constructed of smaller postholes with diameters within a range of 8-15 cm. The opposite shorter rear wall is similar to the wider end, albeit without an entrance; the postholes are between 56-16 cm in diameter.

The external walls on either side display clear opposition to ono another. There are 15 large posts (20-70 cm in diameter) with two or three smaller posts placed between them. The spacing of the larger postholes are between one and two meters. The majority, however, are closer to separations of 1.5 m. This indicates clear planning prior the building of the structure.

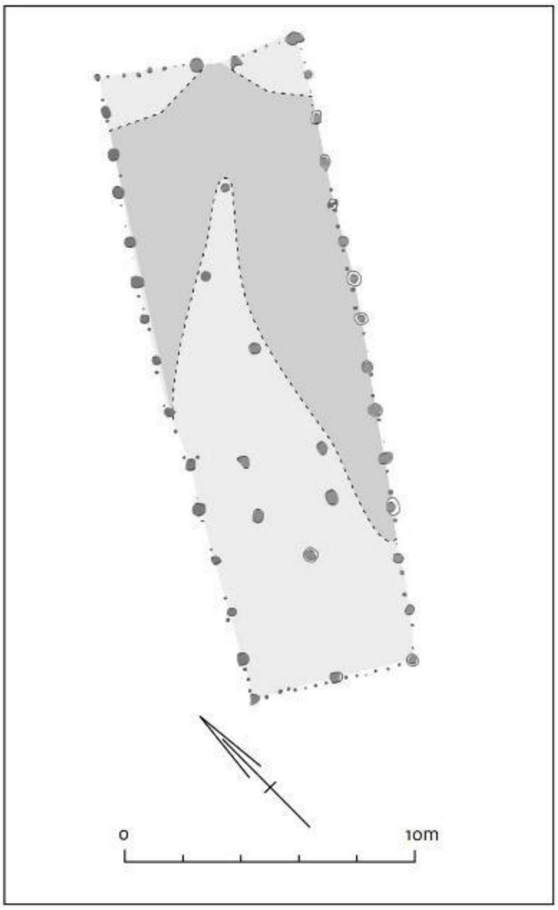


Fig.7: The Zeewijk-East house (Theunissen *et al.* 2014).

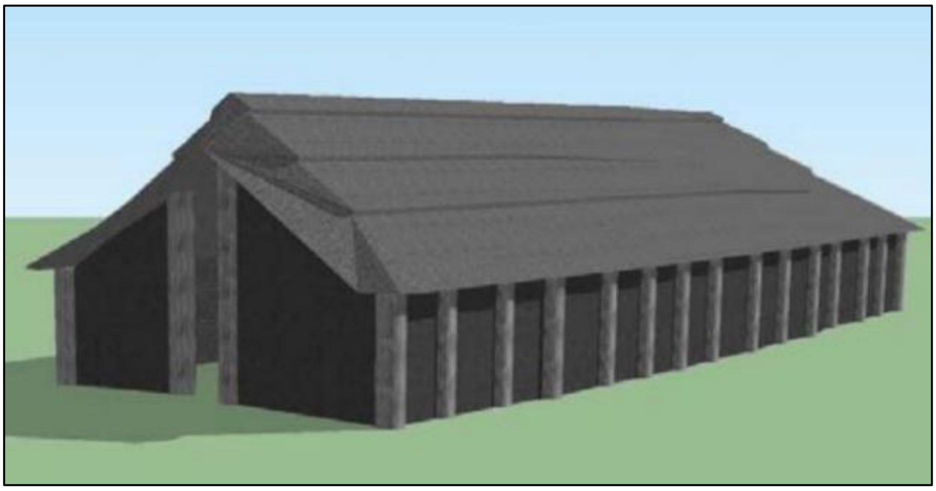


Fig.8: Reconstruction of the Zeewijk-East house (Theunissen *et al.* 2014).

Internally there are numerous small postholes as well as a few larger ones. Four of these form a square just before the penultimate central post in the narrower end of the structure.

Since there are no direct information about the height, the archaeologist suggest highs of 7 m and 5 m. The assumption so far has been that this structure was walled and had a roof. The presence of large postholes with two or three smaller postholes between them may be a framework for wattling.

2.3.3. Scandinavian Peninsula

In the Scandinavian Peninsula during Early and Middle Neolithic (TN I, c. 4000-3500 BC – MN B, c. 2800-2300 BC), people lived both in small huts with U or D shape layout and 3-7 m of length (Larsson and Brink 2012), coming from the Mesolithic tradition (Madsen and Jensen 1984) and in *mesula A-Frame*d houses i.e. those with an inner row of roof-supporting posts. These houses has been divided in Mosby type, Dagstorp type I-II, the Limensgård type (Fig.9). The Mossby type have a length that varies from 10 to 16 m, with an area of 35–130 m², with walls slightly curved and rounded corners. The roof was supported by a row of three stone-lined postholes and smaller posts regularly displaced marked the walls. This type has been found in both the southern and the central part of Scandinavia. The Dagstorp type I house has length that varies from 7 to 16 m, with an area of 30–50 m². This type of house has been found only in the southernmost part of Sweden. The Dagstorp type II has straight long sides and gable ends. The houses of this type measure, usually, around the 16 × 6 m, with small size variation, and 96–130 m². The longest sides of the Limensgård type houses are characterized by having trenches instead of wall posts. These houses seems to be the longest of the three types, with a length between 14–22 m and an area of 50–165 m².

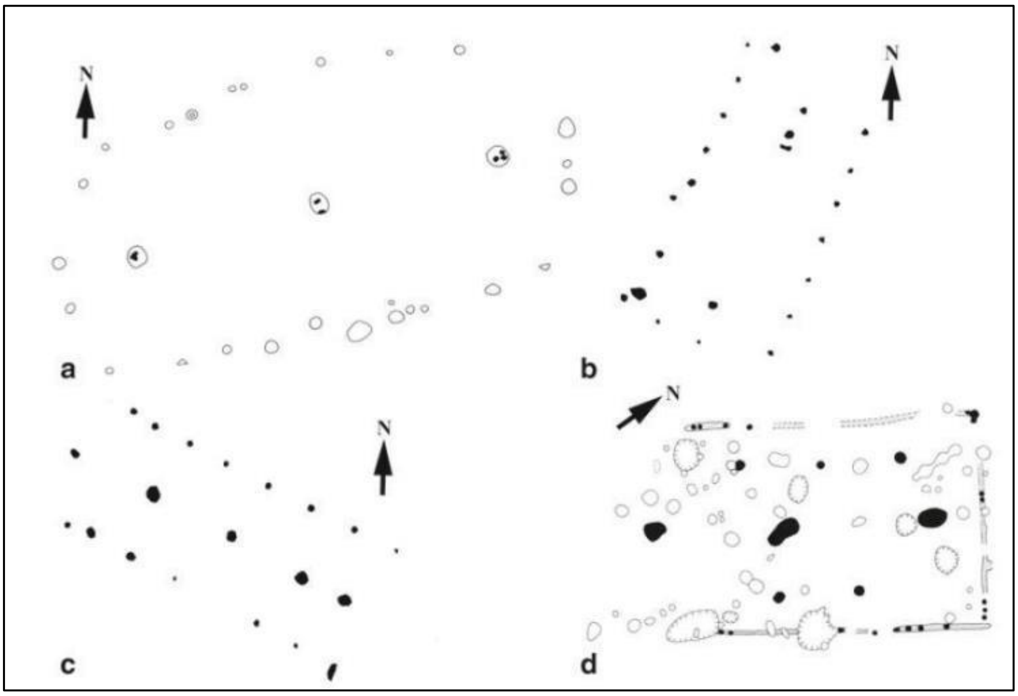


Fig.9: Houses from the Early Neolithic and early part of the Middle Neolithic. **A**: House of the *Mossby* type (Larsson 1992). **B**: House of *Dagstorp I* type (Artursson *et al*. 2003). **C**: House of *Dagstorp II* type (Artursson *et al*. 2003). **D**: House of *Limensgård* type (Nielsen and Nielsen 1985)

2.3.4. Balkan Peninsula

In the Balkan Peninsula, most of the Neolithic settlements were built on flat terraces next to rivers or on tells in marshy areas and rarely in higher areas (Sanev 1994; Tolevski 2009). The houses seem to follow the form saw in the Near East being, generally, freestanding, rectangular and single-roomed, with a size ranging from 11 to 160 m² (Mitkoski 2005; Tolevski 2009). But here, like in the Near East, this "basic model", had multiple variants often connected with the local diversity, thus the house could have squared, rectangular or even elliptical or apsidal plan two or more rooms and with one or two storeys with, in some cases, porches and/or basements (Souvatzi 2013). At Servia (6000 BC), the houses were either square or rectangular with one, two or three rooms. Ground plans measured from 3.5 to 5.5 m in width and from 6 to 10 m in length and were made using different techniques. Storage facilities and cooking structures were part of these houses (Mould and Wardle 2000). The floor types vary from simple beaten earth to stone pile frameworks and wooden planks: at Veluška Tumba (6030-5620 BC) and Amzabegovo (6510-5600 BC) (Simoska and Sanev 1975; Gimbutas 1976) the floor was constructed in rammed earth with flattened pebbles and slab, as at Amzabegovo, Senokos (6500-5500 BC) and Radin Dol (5700-5300 BC) (Gimbutas 1976; Kitanoski *et al.* 1987; Temelkoski and Mitkoski 2006), or using wood, as in Veluška Tumba and Porodin (5500 BC) (Grbić *et al.* 1960; Simoska and Sanev 1975). This insulating layer was covered with clay, enabling comfortable movement in the interior (Naumov 2013). The built techniques used for walls and other superstructures includes mud brick, wattle and daub and pies with foundation made of stone or simply trenches dug into the ground.

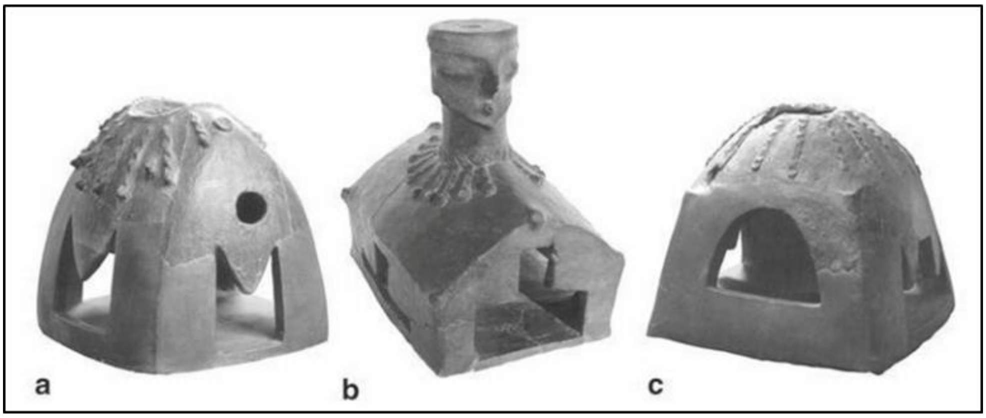


Fig.10: Anthropomorphic house models. **A**: Veluška Tumba, no scale (Vasileva 2005). **B:** Porodin, height 25.5 cm (Kolištrkovska Nasteva 2005). **C**: Dobromiri, no scale (Vasileva 2005).

Direct evidences about roof shape and materials are scarce but the study of ceramic anthropomorphic house models (Fig.10) suggest that roofs could be gabled, double-pitched or flat as at Dikili Tash (6400-5400 BC) (Koukouli-Chrysanthaki *et al.* 1996) made of a wooden structure covered with straw fixed by ropes (Zdravkovski 1990; Borić 2008). The same goes for wall and roof openings: windows, doors and other openings are known only from the clay house models (Toufexis 1996; Toufexis and Skafida 1998). However, it is worth recalling that the numerous openings on the ceramic models could be mainly related to the symbolic significance of the models and their possible function as lanterns (Chausidis 2008; Naumov 2009) rather than recalling real architectonical features. Also the walls build techniques vary considerably: at Veluška Tumba and Porodin large piles and smaller posts arranged in two rows and connected with wattle were used (Simoska and Sanev 1975; Grbić *et al.* 1960). At Madjari, Veluška Tumba, Vrbjanska Čuka, Zelenikovo and Porodin (Grbić *et al.* 1960; Simoska 1986; Garašanin and Bilbija 1988; Sanev 1988; Mitkoski 2005) planks were used instead of posts, while at Veluška Tumba (Simoska and Sanev 1975) they used reeds. The wooden construction was covered with a mixture of mud, clay, chaff or animal excrement (Tolevski 2009). At Amzabegovo, on the contrary, were used mud bricks and stone foundations (Gimbutas 1976).

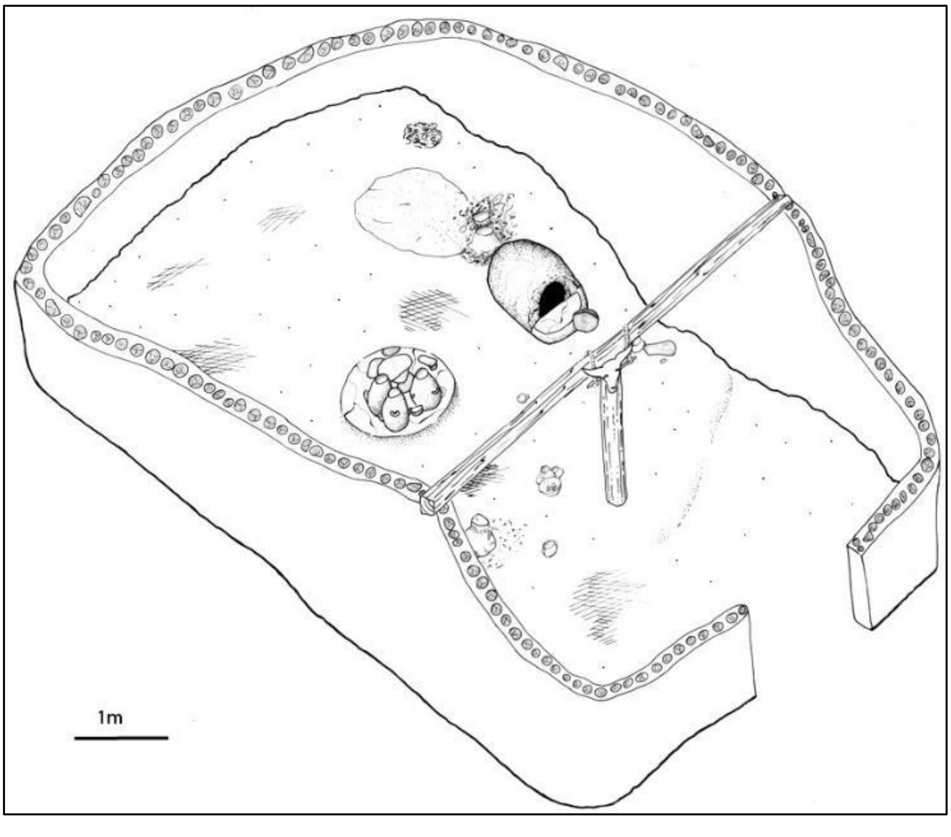


Fig.11: Reconstruction of a house at Dikili Tash site (http://www.dikili-tash.fr).

The interior of Neolithic houses in Macedonia was characterized by a main living area and several rooms separated by thin walls or partitions. Ovens, hearths, bins or granaries where arranged inside these spaces. Such partitions are confirmed in Madjari, Porodin, Govrlevo and Veluška Tumba, but there is not much data on their appearance (Grbić *et al.* 1960; Bilbija 1986; Simoska 1986; Sanev 1988). At Dikili Tash (6400-5400 BC; Fig.11), the walls of houses were constructed in two variations of the post- framed technique, and the different clays used for different domestic constructions (walls, roofs, floors, ovens and benches) were obtained from sources as far as 15 km away (Koukouli-Chrysanthaki *et al.* 1996).

2.3.5. Near East

The firsts examples coming from the Near East, the geographic region where the processes of 'Neolithisation' first crystallized (c. 11.500 cal BP onward), prior to its dispersion as a 'package' to Europe and other parts of the Old World. The Levantine Neolithic is presented in a four phase terminological framework: (PPNA: c. 11.500–10.500 cal BP), Pre-Pottery Neolithic B (PPNB: c. 10.500–8400 cal BP), Pottery Neolithic A (PNA: c. 8400–7500 cal BP), and Pottery Neolithic B (PNB: c. 7500–6500 cal BP). The Near East Neolithic also allow to see how even during the same area and the same period the form of the house could change underling, sometimes, changes inside the group. The passage from the Pre-Pottery Neolithic A to the Pre-Pottery Neolithic B show the shift from the round house to the rectangular one. During the Pre-Pottery Neolithic A the house appear to be circular or oval (Fig.12), semi-subterranean and composed by only one floor, following the architectural tradition of the preceding Natufian period (Goring-Morris and Belfer-Cohen 2013). The structure was made using wattle and daub or, somewhat later, of mud brick on stone foundations with wooden posts and beams to support flat roofing and pisé floors, sometimes with interior partitions (Stekelis and Yisraely 1963; Lechevallier and Ronen 1994; Bar-Yosef and Gopher 1997; Edwards and House 2007; Bar-Yosef *et al.* 2010). Indoor furniture includes stone-lined hearths and ovens, large cup-marked slabs, bins, etc.; there are also external storage silos, sometimes small and sometimes large, i.e. communal (Bar-Yosef and Gopher 1997; Kuijt and Finlayson 2009). As said before it is during the Pre-Pottery Neolithic B that began the shift from the circular plant of the house to the quadrilateral plant (continuing during the

Pottery Neolithic A and B) starting from the site of Motza (Judean hills) followed by Beidha and and Shaqaret Msiad, both at the edge of the Mediterranean province (Byrd 1994, 2005a, 2005b; Kinzel *et al.* 2011).

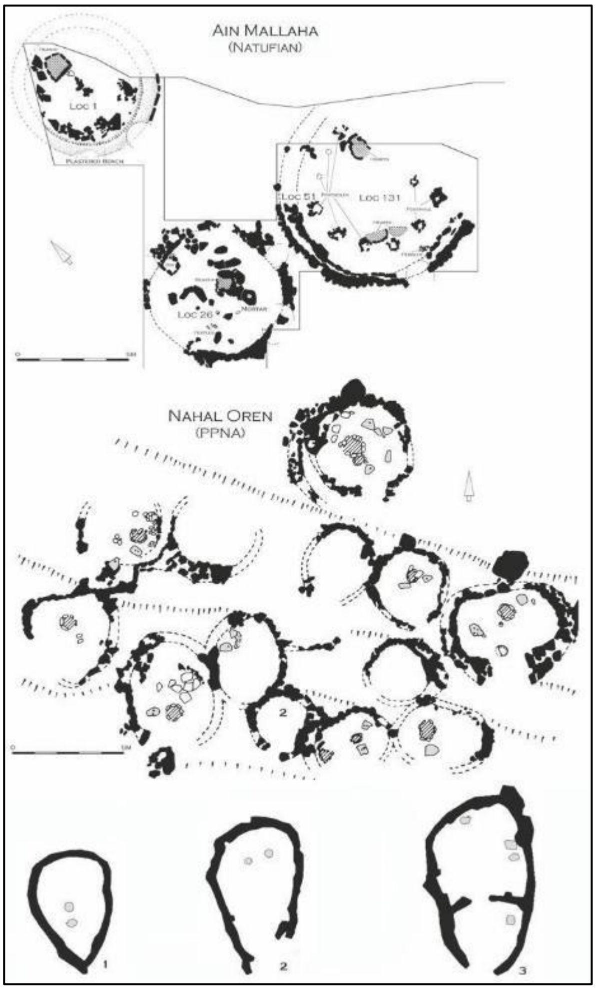


Fig.12. Top: Plan of part of Natufian hamlet at Ain Mallaha (Eynan), Centre Plan of hamlet at PPNA Nahal Oren. **Bottom:** Typical PPNA residential structures at (Gilgal, Hatoula, Netiv Hagdud) (Goring- Morris and Belfer-Cohen 2013).

The quadrilateral base unit was then use to create more and more variants (Fig.13). The houses found at Beidha, 'Ain Ghazal and Yiftahel (Banning and Byrd 1987; Braun 1997; Rollefson 2001; Byrd 2005a) were long-axis 'corridor' house, pier-house or '*megaron*', sometimes two-storied, the second storey composed of one or two larger rooms dedicated to the domestic activities. The semi-subterranean basement, consisted of multiple cells separated by buttresses, was used for storage and workshops. At Basta and el-Sifiya (Mahasneh 1997; Gebel *et al.* 2006) were found enclosed 'courtyard' houses having small cells on the ground floor and entrance through raised doors/windows. On these cells lies the upper floor dedicated to domestic activities. Loose 'pueblo-style' structures were found at Ba'ja, Ain Jammam and Wadi Ghuwair (Waheeb and Fino 1997; Simmons and Najjar 2003; Gebel and Hermansen 2004) on steep slopes ad characterized by houses of two or three storeys. At Nevali Çori and Çayönü (Schirmer 1990; Schmidt 1996) archaeologists found 'long houses' on raised 'grill' foundations. Most of the houses were made of mud bricks walls erected on stone foundations

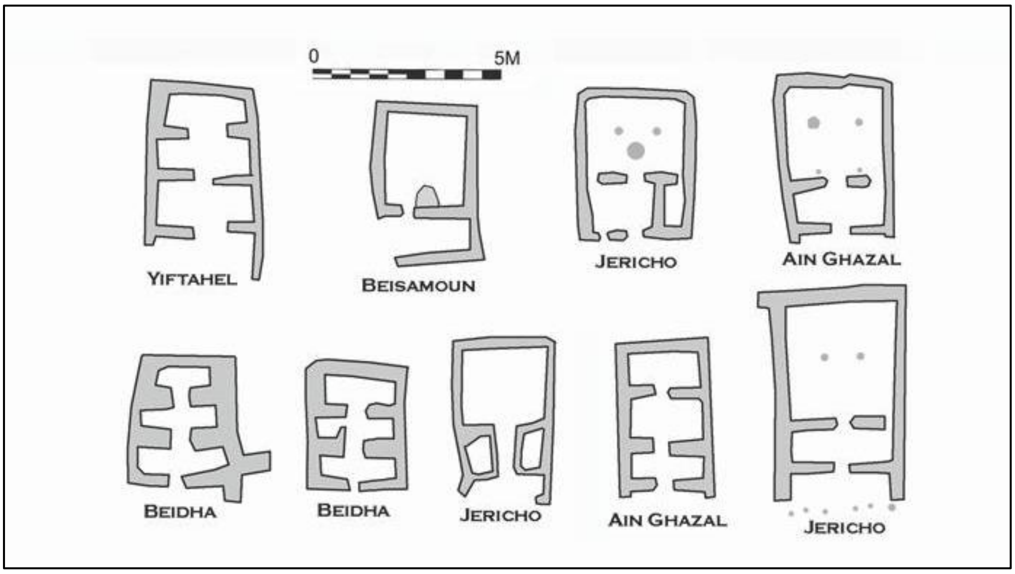


Fig.13: Typical PPNB corridor/pier houses (note that the buttresses often represent the basements of two-storey structures) (Goring- Morris and Belfer-Cohen 2013).

and with raised floors (against rising damp) while in other, like in the structures of south Jordan, dressed stone masonry was used; roofs were flats. In the Mediterranean zone of the southern Levant lime plaster was used for floor and walls (Garfinkel 1988; Goren and Goring-Morris 2008) but also gypsum plaster is commonly used as covering (Kingery *et al.* 1988). Sometimes stone-built channels can be found under some structures probably to prevent rising damp and provided drainage, e.g. el- Sifiya and Basta (Mahasneh and Bienert 2000; Gebel *et al.* 2006). In addition to this is important to remember that small, mobile foraging bands, continue to live in the desert periphery of the southern Levant (Goring-Morris & Belfer-Cohen 2013) occupying seasonally sites with waist-high circular stone built huts and organic superstructures in ‘beehive’ arrangements (Bar-Yosef 1981; Goring-Morris 1993; Betts 1998; Henry 2005), following previous trends of life. The site of Çatalhöyük is located in Central Anatolia, along the course of the former Çarsamba River. The 13 ha site can be dated to about 7300–6200 Cal B.C. (Cessford 2001) and falls mostly into the Ceramic Neolithic in the local culture-historical sequence. Buildings were clustered into blocks. The house entrance was on the roof as evidenced by diagonal marks in the wall plaster of the upstanding walls indicating the former locations of the ladders (Fig.14). The spatial organization of the buildings seems to have been fairly standardized, with the ladder, hearths, and ovens in the southern part of the room. The floors in this area of the buildings are often dirtier and made less carefully than those to the northeast, where one often finds a number of platform compartments (Hodder and Cessford 2004; Matthews 2005). Other elements found in the Çatalhöyük buildings include cupplanks set into the walls, basins, and bins. In some cases, houses had secondary rooms used for storage or contain bins. Based on the sizes of these structures and their inventories, it is plausible that they served as household residences, housing about four to five people (Mellaart 1967; Matthews 1996; Cessford 2005). Additional elements found within these buildings include wall painting (with both simple geometric figurations and human representations) moulded features, especially in the form of moulded clay animal heads and burials located beneath the floors (Düring 2007).

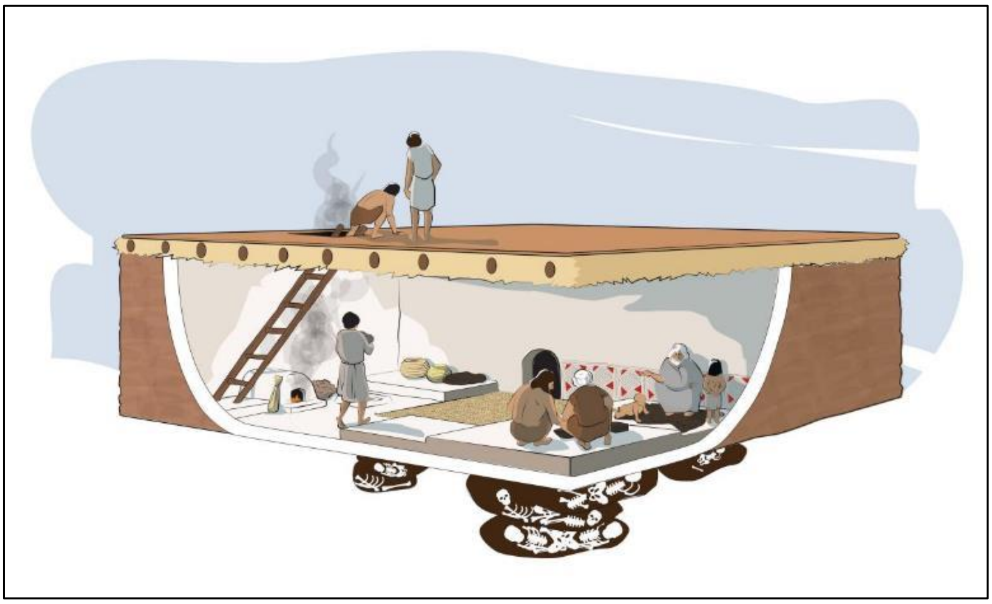


Fig.14: Çatalhöyük reconstruction of one of the houses of the site (http://www.catalhoyuk.com).

2.3.6. Asia – Japan & China

Even if Far East Neolithic is quite different from the Neolithic in Western and Near Eastern regions, we decide to include some examples of houses not so much for historic relations but for their potentiality in facilitate ethno-historical comparisons.

Japan

In Japan, the Neolithic come under the Jomon period, a long era that last from ca 10.500 BC (Incipient Jomon) to the c. 300 BC (Final Jomon). Its name is derived from the “cord markings” that characterize the ceramics made during this time. The Neolithisation process of Japan was different from the Neolithisation of Europe, West Asia and China where farming, pottery and sedentism has been considered the basis of the civilized society (Nishida 2002). In Japan pottery first appeared around 13.000 years ago, with sedentary villages appearing at around 10.000 years ago but agricultural practices did not begin until 2500 years ago (Imamura 1996). One of the most significant site of this period is Sannai-Maruyama site (Aomori Prefecture, northern Japan) occupying an area of 38 ha (Fig.15). The site dates primarily to the Early and Middle Jomon period (Okada 1995) and was occupied from c. 5900 to 4300 BP (Imamura 1999; Tsuji 1999). For what concern the Neolithic period different type of houses has been discovered: Early Jomon: pit-dwellings oval or rectangular in plan associated with ground hearths. More than 700 pit-dwellings (total and through all the 1500 years of occupation) has been discovered (Habu *et al.* 2001). Middle Jomon: the settlement reach its maximum: pit-dwellings (Fig.18); 11 long-houses: large rectangular pit-dwellings some of which measure over 30 m in length and 10 m in width appears and will be present throughout all the Middle Jomon occupation of Sannai Maruyama (Fig.16). Most of these houses are located at the central area of the settlement. Both large rectangular pit-dwellings and regular-sized pit-dwellings from the Middle Jomon period exhibit evidence of frequent rebuilding and enlargement; 120 so-called “raised-floor buildings”: sets of six post-moulds that are placed in a rectangular plan (Fig.17). There is no evidence of a floor associated to any of these features and most of the archaeologist assume that were constructed above ground surface supported by posts driven into the ground (Miyamoto 1995). The diameter of each post-mould measures about 1.8 m and the average depth more than 2 m. at the bottom of each post-mould was the base of a large post made of chestnut wood, the diameter of which measures 75-95 cm (Okada 1995). These structures are located on the edge of the river terrace in the north-western part of the site, in the central area of the settlement, and to the southwest of the South Earth Mound. Remains of raised-floor buildings in the central area show particularly low diversity in size and plan (Okada 2003). Examination of these remains indicates that at each phase of the Middle Jomon period approximately four or five of these buildings were in use simultaneously. Some of the houses forms two rows oriented north south. Some scholars supposed that he structures were not houses but, instead, towers (Miyamoto 1995).

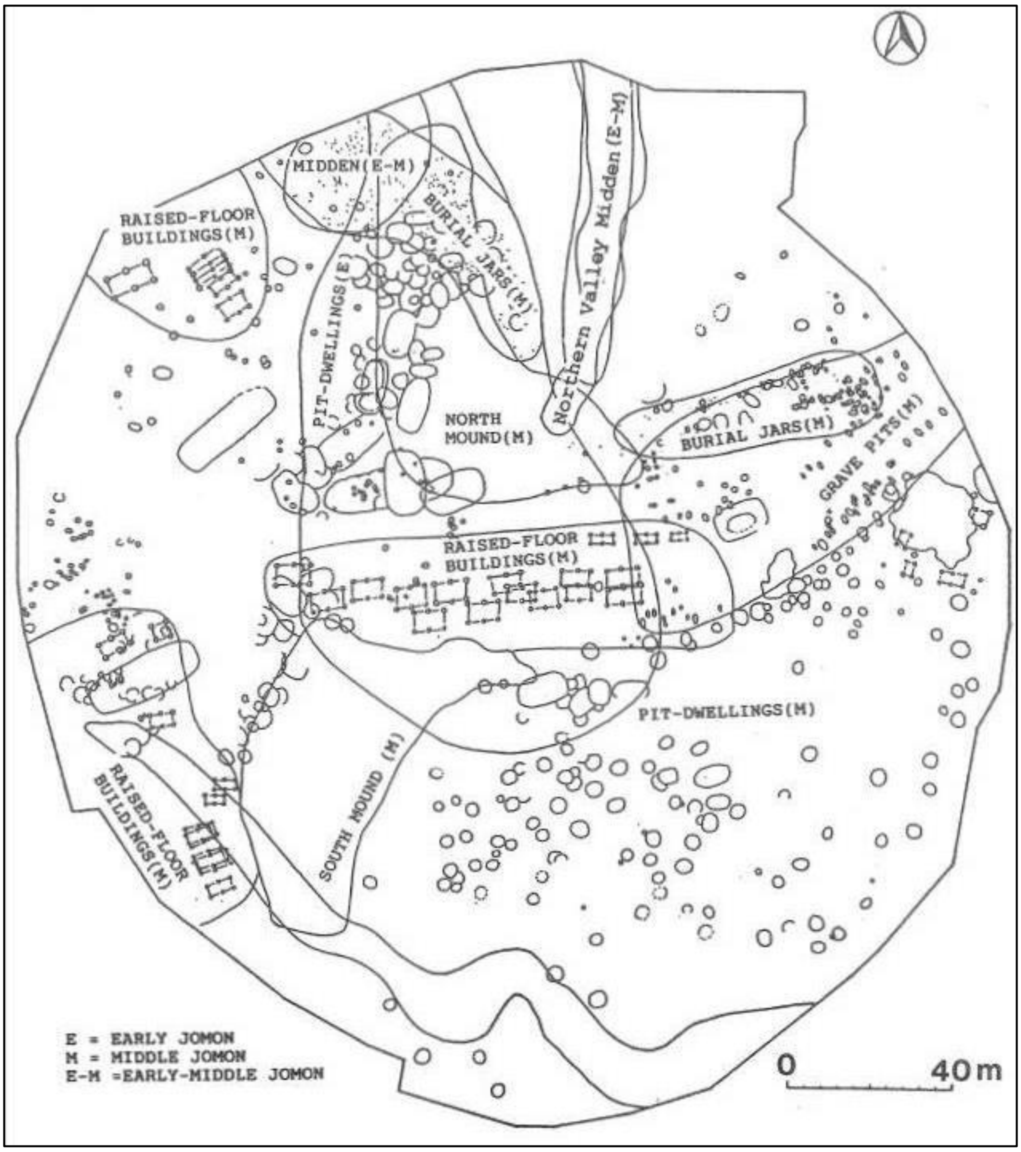


Fig.15: The Sannai-Maruyama site and the distribution of its features (Habu *et al.* 2001).

Fig.16: Reconstruction of one of the Japanese Sannai Maruyama long house (https://commons.wikimedia.org/wiki/File:140913_Sannai-Maruyama_site_Aomori_Japan02bs5.jpg).

Fig.17: Six pillars house reconstruction, Japan (https://www.flickr.com/photos/birdies-perch/1708315687/).

Fig.18: Two different types of pit dwelling, Japan (https://www.flickr.com/photos/birdies-perch/1708313827/; https://www.flickr.com/photos/birdies-perch/1709167384/).

China

One of the most important late Neolithic site of China is the village of Pan-po (4500 BC) located at Xi'an in the Chinese province of Shaanxi (Haskins 1957; Nai 1963). The hamlet of Pan-po is situated on the right (eastern) bank of the Chan, a tributary of the Yellow River. The houses were grouped around a large rectangular building probably a clan building or a communal lodge with function of storehouse as well (Fig.19). The houses were of two types: circular and square in ground plan. The circular type was the most diffuse and the building technique used was more advanced than the one used for the rectangular houses. Nevertheless, they had these common features: the main doors of all houses opened to the south; two very low partition walls were found in each house just inside the door; in the centre was an oven-like pit, which served as a fireplace. These features are similar to those found today in the houses of many of the minority people (Hsing-pang 1959). The circular huts were small, about 5 m of diameter, with walls of wattle and daub. Among the circular houses, one was better preserved, the roof having been crushed in. The debris consisted of the remains of a wooden beam, and a layer of burnt clay bearing the impressions of reeds. The walls were exceedingly thin, 5 to 10 cm, reaching only 38 cm at the highest point. The elevation could not be determined but the batter of the walls suggested that the circular houses were beehive shaped. In the centre of the floor was a pear-shaped oven. The floor and the inners surface of the walls had been finished with a thin coat of white plaster. There was no trace of decoration on the walls. The entrance, on the south side, was provided with a narrow porch, 70 cm wide. The porch was separated from the main walls by thin partitions. The rectangular and square houses, even if probably later in date (Haskins 1957), shared common characteristics with the circular ones. They had about the same size, measuring 4 to 5 m on each side; the entrance was still to the south and provided with a porch and the floors; walls were plaster finished with no trace of decoration and the centre of the room again contained an oven around which were scattered many potsherds. However, they had rounded corners and the walls were considerably thicker, made of rammed earth, which showed traces of having been fired. The squared houses had the floors dug about 1 m below the original ground level and stairways led from the main room to the porch. Near the centre of each main room was a single hole which had served as the footing of a supporting column. Some of the rectangular houses were raised due to the superimposition of buildings at different times. In these cases, the underground portion would be above the mean ground level.

The largest building excavated at Pan-po was the so-called "clan lodge", probably the home of a tribal chieftain. Twelve wooden columns of 15 to 28 cm in diameter supported the roof and traces of wooden planking has been found. As for the other houses, the entrance was on the south side and porched. The main room was divided roughly in half by an east-west partition wall. Even if the westerner end of the structure had been washed away, the archaeologists estimated the length to have been about 20 m from north to south. The walls were 1 m thick and made of fire-baked clay.

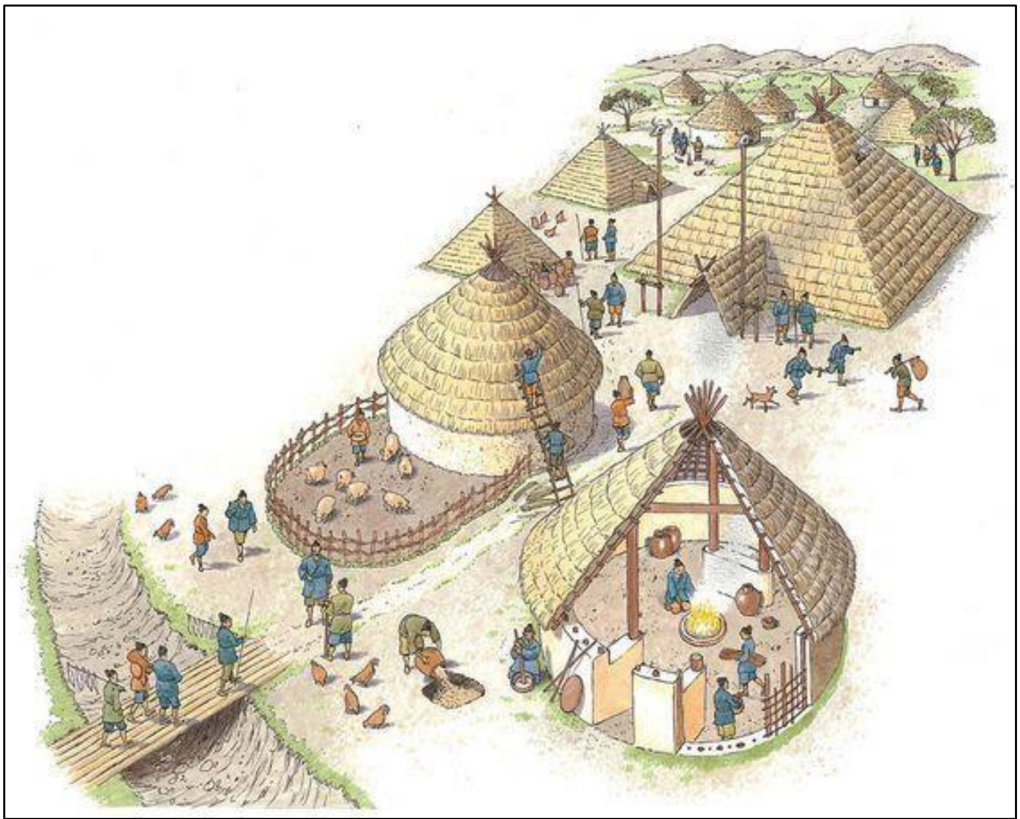


Fig.19: Reconstruction of the village of Pan-po (curiousstoryofourworld.blogspot.com), China.

2.4. NEOLITHIC WETLAND OCCUPATION AND PILE DWELLING

Completely different ways to build were used during the Neolithic in wetland environments. Since the prehistory, wetlands environments (swamps, shores, marshes and bottomlands) have been appealing to human groups as proved by the fact that, since the Early Palaeolithic era, a large number of sites in Europe could be identified in such kind of environment, as the case of Torralba in Spain, Boxgrove in England and Bilzingsleben in Germany (Coles 2004b). The "secret" of this appeal, lies in the nature of these areas that includes the basic needs for the development of a settlement: resources diversity, productivity and reliability (Niering 1985; Forman and Godron 1986; Nicholas 1988; Nicholas 2003). Sometimes other aspect like defence, socio-economics aspects and beliefs (Nicholas 1988; Coles and Coles 1989, 1996; Nicholas 2003; Menotti 2012; Menotti and O'Sullivan 2013) might have probably driven the interaction between people and wetland. Even though these first examples of wetland occupation in the Holocene, particularly in the Mesolithic, such as at Starr Carr, in England (Clark 1954; Coles 2004a), a few sites on Feder Lake, in southern Germany (Schlichtherle 2004) and some cases in Lithuania (Menotti *et al.* 2005), the large-scale settling of lacustrine environments in Europe occurs starting from the Neolithic (Menotti 2004). The building forms (on the base of the reunited theories of Reinerth (1932), Paret (1958) and Vogt (1955) have been grouped in three main construction styles: houses built on the ground, houses with slightly raised floors or houses on piles (true lake dwellings). In this study, I focused the attention on the latter type of house, the pile dwelling type. The archaeological record of this structures is limited due to building materials (primarily wood) and their architectonical forms that left few traces upon the ground: what basically left are the holes of the posts holding the upper structures and, in some fortunate cases, the piles themselves with collapsed structures, preserved underwater.

Fig.20: The relief of Deir-el-Bahari describing the expedition to Punt organized by Queen Hatshepsut (https://luxor-dream-tours.de/ausfluege/ausfluege-in-luxor/luxor-westbank/tempel-2/tempel-hatschepsut/).

Archaeology can tell us the size of such buildings and the form of their footprint on the ground, but it can give us only the most speculative impression of their three dimensional form. Anthropology can give us convincing image of recent examples, but the extrapolation of these into the past must again be highly speculative. In fact, so far, the oldest reliable evidence of a pile building and its forms in our possession is a relief from the Mortuary Temple of Queen Hatshepsut (1507-1458 BC; Fig.20) at Deir-el-Bahari (Theban Necropolis, Luxor, Egypt) about the expedition to Punt (probably modern Somalia) authorized by the Queen (Hayes 1966). It show domed huts, presumably thatched, standing on piles over or close to what appears to be a schematic representation of water. However, despite its archaeological importance, this relief is unhelpful when it comes down reconstructing the Neolithic pile dwellings. What has been said so far shows the problems that arise when it comes to interpreting a pile dwelling or a pile dwelling settlement. However, in some cases there are pile dwelling sites giving us information about this way of life, as the following examples could depict.

In the In the Circum-Alpine the village of Clairvaux-Station II (3500 c. BC; France) was composed by two different areas with two different type of rectangular structures: a land area and an islet (Pétrequin 1988; Fig.21).

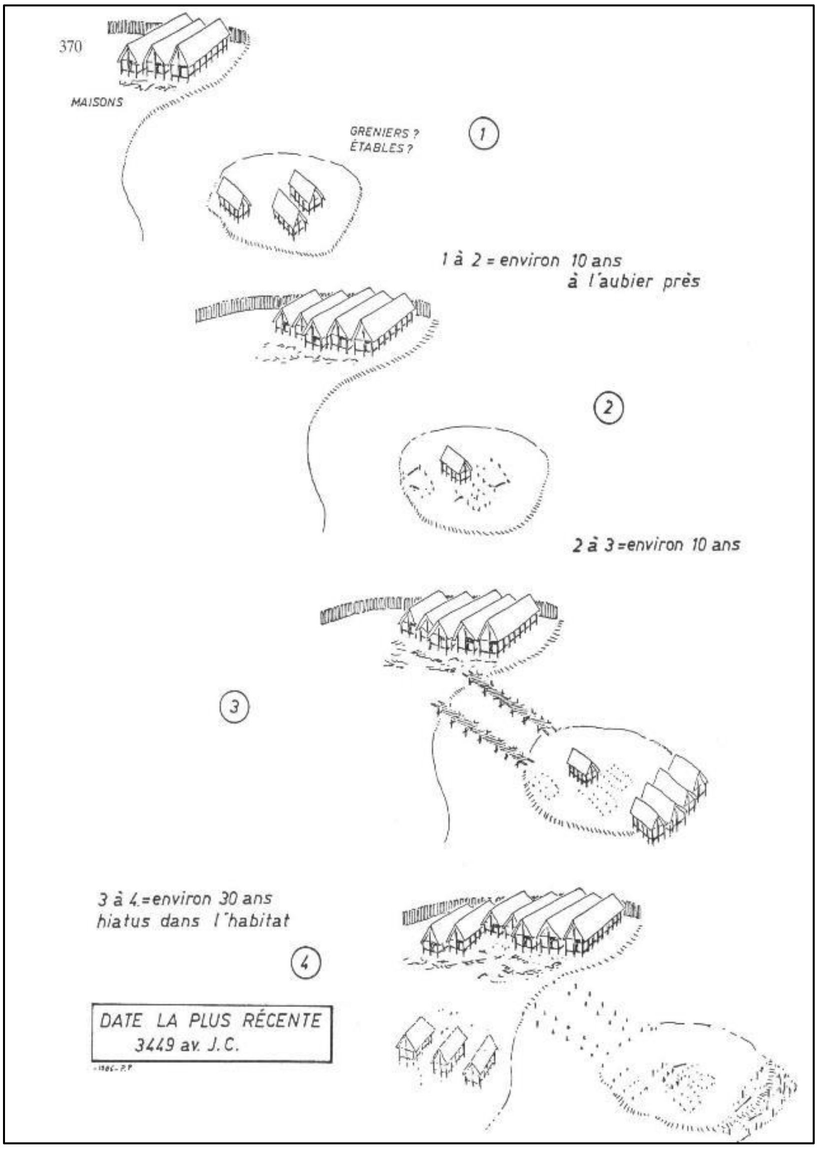


Fig.21: Clairvaux-les-Lacs (Jura), stations II. Settlement chronological evolution (Pétrequin 1988).

The land area, enclosed by a palisade, was occupied by one row of houses parallel to the shore. The houses were 13 m long and 4 m of width and they laid on three longitudinal rows of posts that, along the walls, were set in couples. The diameter of these piles rage between 7.5 cm and 14.5 cm. The roof were probably made of a wooden structure and for the covering was probably used bundles of local vegetal material like straw (Lundstrom-Baudais 1986), reeds or unwind bark. The walls structure consisted of a framing made of crisscrossed wooden elements. The wall covering was probably made of clay mix to vegetal fibres or using straw reeds or unwind bark as for the roof.

The islet lies in front to this area and was occupied by a group of small buildings, probably storages. The two areas were linked by two wooden plank walk.

The Niederwil village (4000-3500 BC; Switzerland), on Lake Egelsee, covered an area of c. 2000 m², had an oval form and was surrounded by a strong palisade (Waterbolk and Van Zeist 1978; Waterbolk and Van Zeist 1991). There were 35 houses of average size of 11 by 5 m set on six rows separated by alleyways with the fronts of the houses standing closely side-by-side. The houses, generally, had 2 rooms. The base of the houses was made by horizontal planks held by piles driven into de ground at intervals of 1 m. At Sutz-Lattrigen, on the Bienne Lake (Switzerland), has been identified more than twenty Neolithic villages many with building-structures still clearly definable (Fig.22), and their absolute dating between

Fig.22: Sutz-Lattrigen, Riedstation. Year by year evolution of the buildings of the late Neolithic settlement between 3393 und 3389 BC. Colours indicate building dates. Red: 3393 BC. Yellow: 3392 BC. Blue: 3391 BC. Green: 3390 BC. Magenta: 3389 BC. Dendrochronological record

ends one year later 3388 BC (Hafner 2013).

3800 BC and 1600 BC (Hafner 2011; 2012; 2013). These villages (like the "*Riedstation*" (3393-3388 BC) and the "*Hauptstation*" (3825-3013 BC)) had similar basic structures: a row of bigger buildings, measuring between 8 and 12 m in length, built closely together and a second row of significantly smaller buildings (probably storages) at some distance. All the buildings were arranged with their roof ridges at right angles to the shore (Hafner 2012). In the "*Hauptstation*" a group of eight houses surrounded by a palisade.

The pile dwelling of Torwiesen II (3283-3279 BC), on the Federsee Lake (Germany), was a dense cluster of twelve houses and three sheds lined in two parallel rows along a rather narrow lane. The buildings had rectangular plans with lengths between 3 and 7 meters (Fig.23).

Fig.23: Reconstructed pile dwellings of the site Torwiesen II, Bad Buchau, Lake Federsee, Baden- Württemberg, Germany (http://www.federseemuseum.de/).

While the three biggest houses were double aisled, the other dwellings were just single aisled and of gradual smaller size. Moreover, the biggest houses were built using oak and ash while the other using wood of lesser quality as birch, alder or willow. The walls were made by wickerwork coated with clay. The floors were made of layers of bark partly impregnated by some kind of immature asphalt of local origin (Schlichtherle and Hohl 2002; Dosedla 2016). The Early Late Neolithic pile settlement of Hornstaad Hörnle IA (3922-3902 BC) is located on the shore of the western part of Lake Constance (Baden- Württemberg, Germany) at the tip of a peninsula (Fig.24). The excavated part of the village belonged to a transitional phase between the Pfyn and Horgen cultures that was hardly known previously (De Capitani *et al.* 2002). Ground plans of over 20 houses has been found (Jocomet and Brombacher 2005).

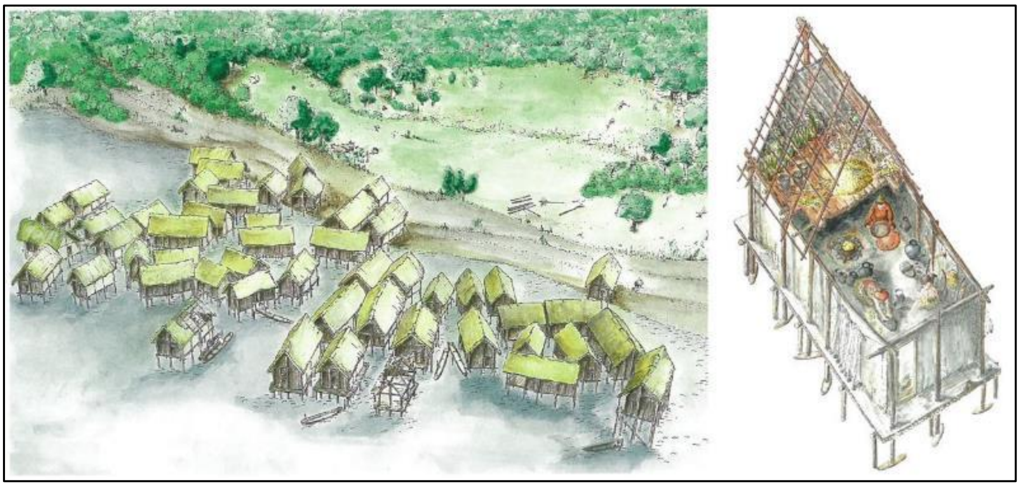


Fig.24: Reconstruction of the Hornstaad-Hörnle IA settlement (Verlag 2016).

The Keutschacher See site (4200-3650 BC), in the administrative district of Klangenfurt-Land (Carinthia, Austria) is not only the first known lake settlement of Austria, but also the one with the oldest dendrochronologically confirmed dating (Hirmann 1999; Menotti 2004; Sherrat 2004; Ruttkay *et al.* 2004; Gleirscher 2014; Novak 2016). The site is situated on top of an underwater hill covered with a thick layer of lacustrine chalk sediments where more than 1.600 posts, still in situ, have been discovered. The posts were driven into the lake floor for 30 cm. and were made of round logs with a diameter ranging between 15 and 25 cm and some of them were standing in groups of two or three. Unfortunately, the piles do not show any arrangements that would allow us to ascribe them to particular buildings. Always in Austria, on Lake Attersee, lies the two Neolithic stations of Abtsdorf II (3635-3030 BC) and Abtsdorf III (3654-3104 BC) respectively 60 m and 80 from the shore (Czech 1977, 1982; Ruttkay 1982; Hirmann 1999). The pile dwelling settlement is about 110 m long and 80 m wide, with its shore side boundary not clearly defined. The floor of the houses were built on a supporting framework that was fastened into the lake floor with pegs. In some cases, the floors would only have been raised 20-30 cm (Offemberger and Ruttkay 1997). At Misling II (3695-3127 BC), Weyregg-Landungssteg (4000-3500, 3500-3000 BC) both on Lake Attersee, and Schärfling (4000-3500 BC, on the shore of Lake Mondsee, Austria) has been found structure similar to the ones of the Abtsdorf stations: log frameworks secured into the soil with pegs serving as the foundations of the huts (Ruttkay *et al.* 2004). These foundation structures were meant in order to compensate the instability of the lake floor (calcareous mud). Many traverse beams with recesses were found, which indicated rectangular huts with wattle-work wall that averaged 3-4 m in length (Offemberger 1981). In the settlement of See on Lake Mondsee, macrobotanical samples found, largely of fir, suggest that fir branches were used as insulation on hut floors and in the walls (Pawlik 1993).

At the Neolithic site of Maharski prekop (ca 3500 BC) on the Iščica floodplain (Ljubljana Marshes, Slovenia) there were 2332 vertical piles recorded on the site, which means that average vertical pile density is almost two piles per square meter (Velušček 2013) (Fig.25). Among all these piles can be identified different features. A linear arrangement of piles can be observed over most of the undisturbed part of the excavated area. Here, piles are organized in parallel rows, three at a time, long 8–10 m and spaced 1.7–2.4 m apart. The majority of the piles have a diameter of 5.8 cm, although piles with diameters up to 26 cm can be found. Larger diameter piles are often split (28% of all piles). The longest piles were drive up to 3 m into the silt (Bregant 1974). Other three linear concentrations of piles, running along the channel on the eastern side of the excavated area, has been found. The piles of these structures have, generally, smaller diameters than those in the central part of the excavated area and split piles are almost non-existent (5%).

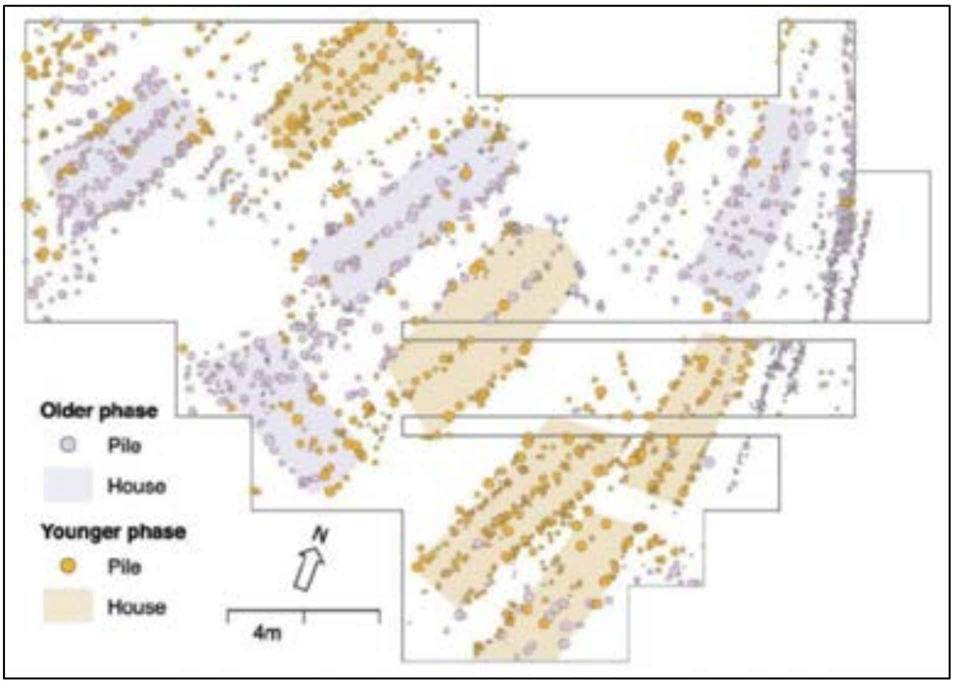


Fig.25: Maharski prekop. Phasing of piles and houses based on the relative heights of the piles. Map is based on excavator's original documentation and published report (Bregant 1975).

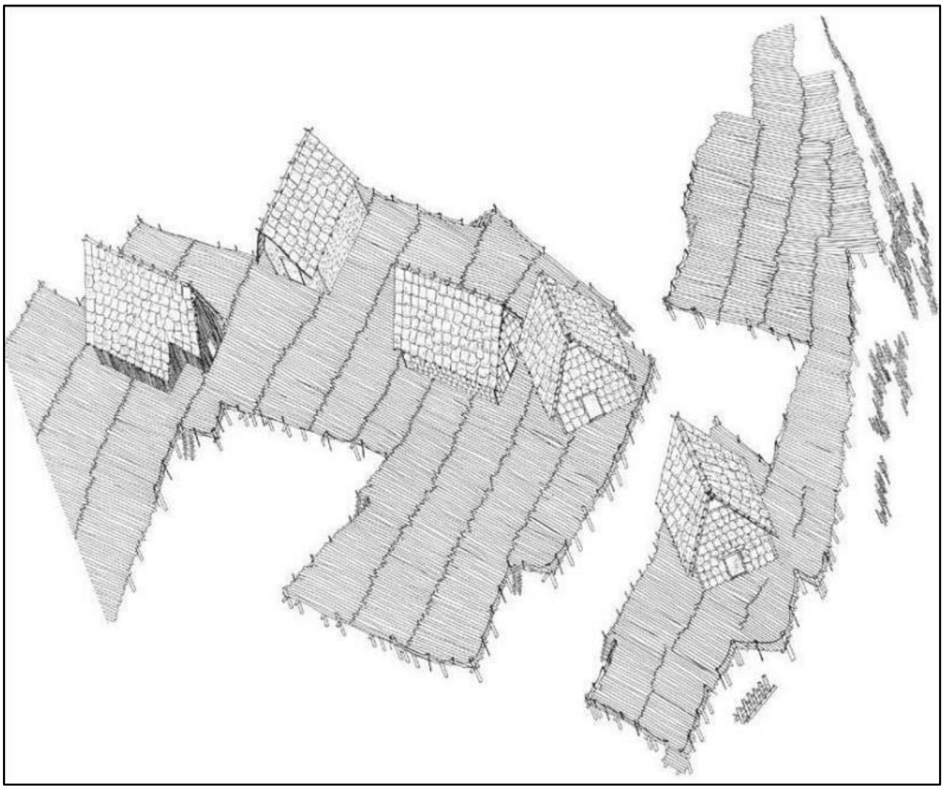


Fig.26: Maharski prekop. Settlement reconstruction (after Bregant 1996).

The excavator interpreted these structures as a revetment (Bregant 1975), which seems reasonable, considering the evidence of the paleo channel. Another notable feature are clay floors, often-burned (Bregant 1974; 1975). These surfaces reach, as maximum, the 20 cm of thickness and cover large areas between rows of piles. Rests of charcoal, wood debris, parts of superstructure, pottery and bone, stone and querns has often found upon these surfaces. The archaeologists established that all these remains could be connected with a group of houses with sizes of around 8-10 for 3.5-4.5 m arranged parallel to each other with, at least, one house oriented perpendicularly to the others. Each of these houses was composed by three rows of structural timbers, with a central row of centre-posts supporting a roof ridge pile; the lateral rows are wall posts (Fig.26). The pavements were, very likely, made of clay and the stone found upon them, were probably part of fireplace, located in the front or in the back of the houses.

In the Western Baltic region, the site of Koorküla (3300–3200 BC), on Lake Valgjärv (Estonia), the remains of a pile dwelling have been found on a rectangular underwater area of c. 732 m^2 (Kriiska and Roio 2011). The remains include logs of coniferous wood 9 m long and with a diameter of up to 30 cm. In between the logs, posts and finer piles of up to 20 cm in diameter were placed half diagonally, laying in the bottom sediments. The lower ends of the piles were sharpened with an axe. In the north-eastern part of the area covered with logs a pile of burnt stones was found, probably belonging to a hearth (Selirand 1985).
In the basin of the Upper Western Dvina River region, 30 pile settlements in total has been found (Miklyaev (Микляев) 1969; 1995). A unique culture of pile dwellings sites was formed here at the end of fourth millennium BC. The main information was gathered during underwater excavations of the site Serteya II (2470-2300 BC) in Smolensky region (Fig.27). (Mazurkevich and Dolbunova 2011; Mazurkevich 2013; Kulkova *et al.* 2015). The houses laid on rectangular platforms of c. 7 by 4.5 m. Piles and forks held these platforms. Pieces of rope, made from bilberry rhizome, has been found pressed between the piles suggesting that were used as connection of the wooden parts. The basis of the platform consisted of logs 9 to 12 cm in diameter, oriented west-east. Piles 5 to 8 cm in diameter were densely laid on the logs in transverse position. Treated

pine slabs about 6 cm thick were placed above at right angles to the piles. A layer of moss lay above, strewn with coarse-grained white sand 8 cm thick. On the sand has been found a hearth formed with big stones laid out in a circle about 53 cm in diameter. Some of the pillars were used as basis for the walls and they had diameters ranging from 8 and more than 20 cm. The larger pile were mainly positioned at the corners of the platforms while pairs of smaller pillars, were placed between them along the perimeter. Those parts of the platforms where sand was collocated, in order to set the hearths, were strengthened with pillars and supports. Spruce and ash were generally used to make the piles, more rarely pine, elm, maple, oak, willow, birch and poplar (Kulkova and Mazurkevich (Колосова, Мазуркевич) 1998).

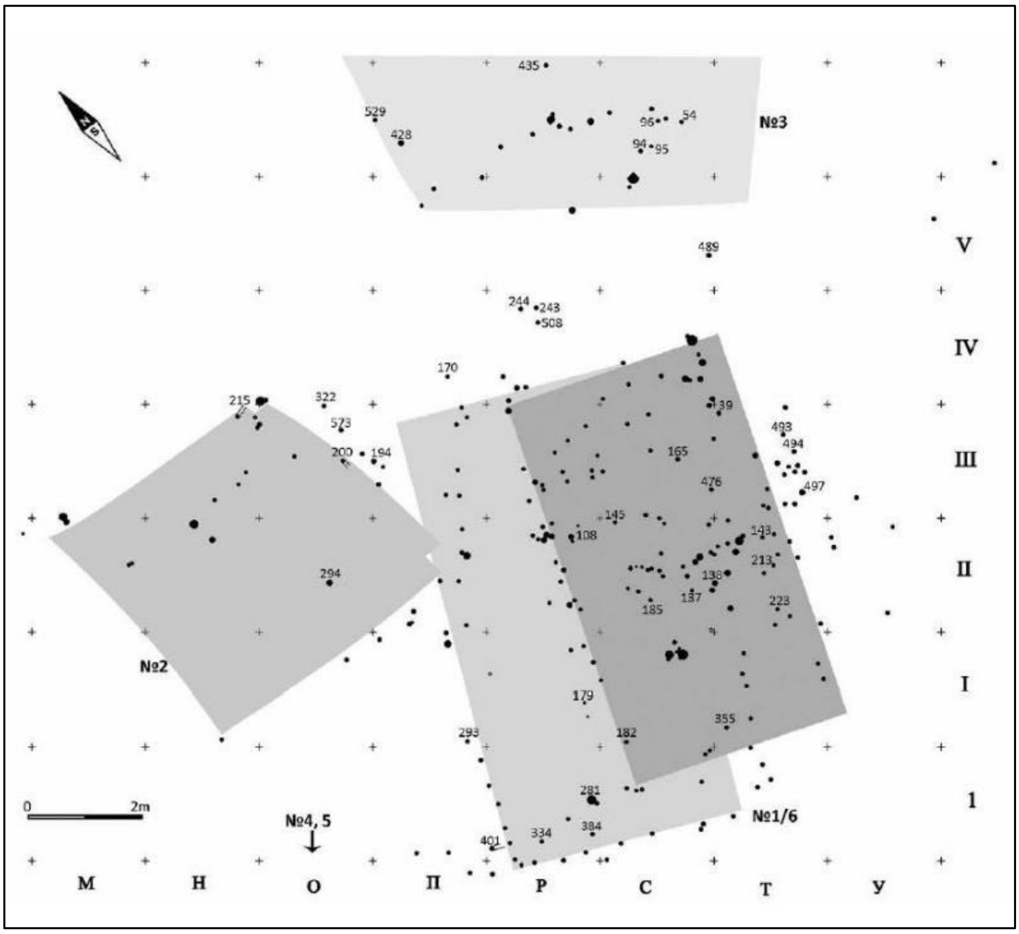


Fig.27: Plan of constructions on the site Serteya II with the indication of piles number used for dendrodating (Mazurkevich 2014).

In addition, fragments of eaves and slabs with a lateral support for floors, and beams with holes, were found. The walls could have been made of branches cleaned from lateral branches a large amount of which was found in the cultural layer, generally laying near rows of piles. The platforms were encircled by rubbish dumps full of kitchen waste located along one of the short walls and adjacent parts of long walls. Several dwellings existed simultaneously on the site.

The site of Veksa (on the confluence of the River Vologda and its tributary River Veksa, Vologda province, Russia) has an exceptional importance for the reconstruction of prehistoric and historic cultural developments in the North-Eastern European forest zone (Nedomolkina (Недомолкина) 2006; Nedomolkina and Piezonka (Пиецонка) 2010) due to the clearly stratified sequence starting in the 6th millennium BC and covering all periods from the Early Neolithic to the Early Middle Ages (Недомолкина 2014) (Fig.28). The site extends c. 2 km along the left bank of the River Vologda, its upper part west of the mouth of the River Veksa is called Veksa I and the lower part of the complex east of the tributary's mouth is called Veksa III. In Veksa III well-preserved wooden piles has been discovered and dated to the Neolithic/Eneolithic period (Недомолкина 2006). The piles are distributed in several clusters along a 350 m long stretch of the left riverbank between the Veksa mouth and the eastern part of the Veksa III site. Even if these piles has been discovered in the shallow water, it is very likely that many more posts and stakes are preserved under water still to investigate. On the contrary, on the landside, the posts continue into the riverbank sediments. Altogether, a total of 1.802 piles and rods were documented, 786 with diameters between 0–3 cm, 402 with diameters of 3–5 cm, 569 with diameters of 5–10 cm, and 45 with diameters of 10–15 cm. The larger posts consist of natural tree stems, in some cases with the bark still preserved, with a round cross-section. The lower ends of these posts have been pointed with axe blows. The smaller rods and stakes are mainly split timbers and have a rectangular cross-section. The largest concentration of posts is covers an area of c. 65 x 10 m. Posts with diameters between 5 and 15 cm are distributed over larger areas and are partly arranged in straight parallel and perpendicular lines. The orientation of these structures does not exactly correspond to the course of the river but is slightly offset, indicating a change of the river course since the time of building of the pile construction. At the moment, possible interpretations of the structures formed by the larger piles include constructions for fishing as well as building remains or platforms for buildings.

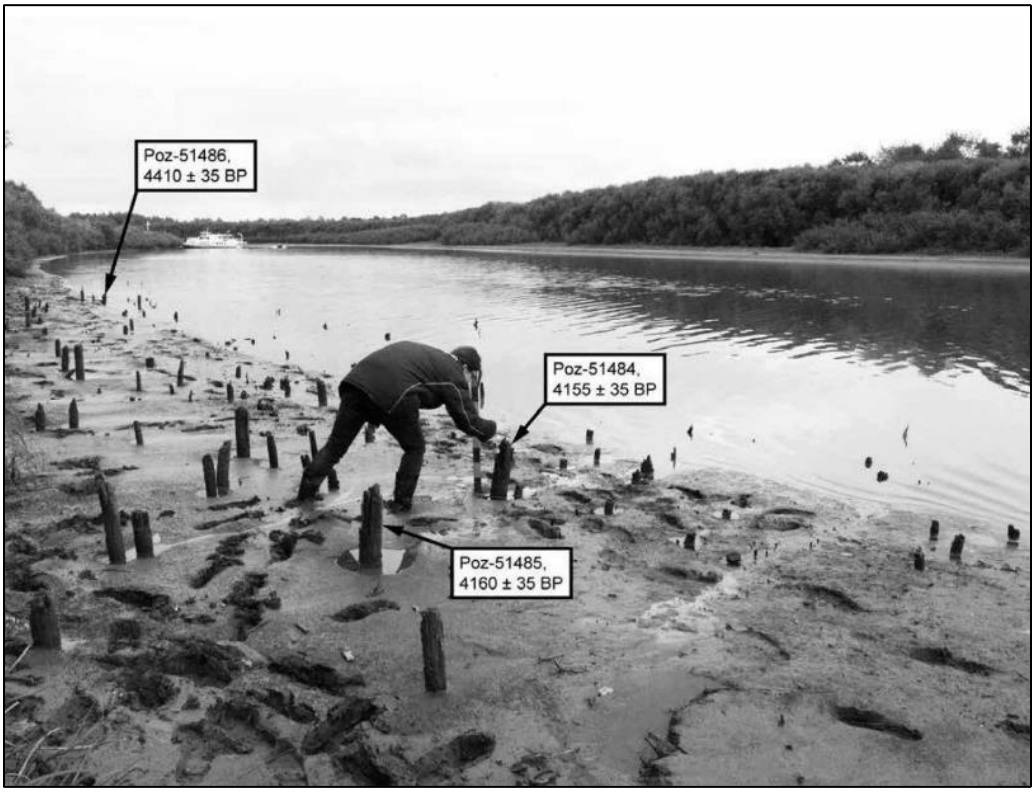


Fig.28: Location of the piles in the main concentration at Veksa III, which were sampled in August 2012 for AMS radiocarbon dating, and dating results (photo: N. G. Nedomolkina).

In the Mediterranean area we can find the site of Dispilio (5500-3000 BC), Greece, on the shores of Lake Orestis (Fig.29). The information we have indicate that the pile dwellings were built using piles to hold the flooring system. The walls, instead, were made of mud brick. The covering system was probably made of wooden element and/or organic plant material (Touloumis *et al.* 2003).

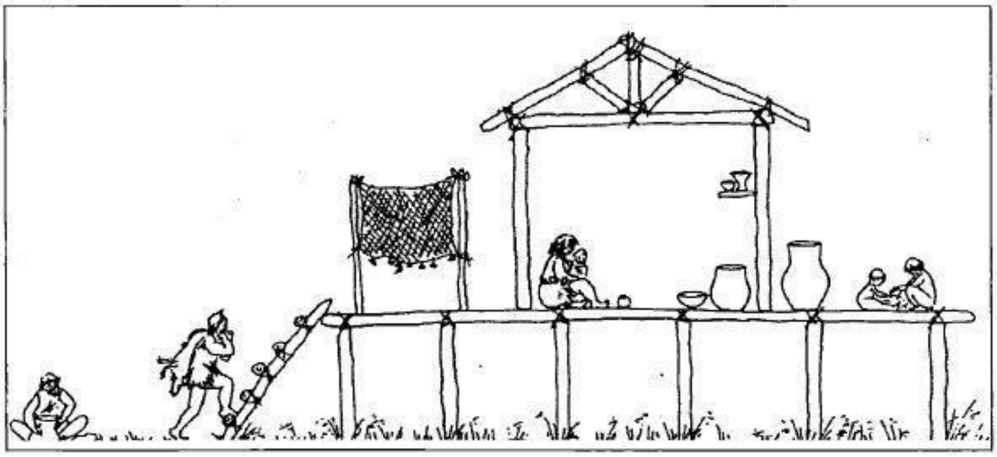


Fig.29: Reconstruction of one of the house of Dispilio (Touloumis *et al.* 2003).

The next two examples came from Asia. Despite the distance is interesting see the similarities between these sites and those seen before.

At Hemudu (5500-3300 BC), in China (Zhejiang Province) houses were constructed on piles, and the surviving parts reveal a developed system of mortise and tenon construction, together with the use of dowels (Fig.30). One of these houses (Layer 4) was 23 long and 7 m wide and had a porch attached 1.3 m wide. The house floors were covered with reed mats, many fragment of which have survived (Jun 1985; Liu and Chen 2012). At Shangshan (9400-6660 BC; Qu’nancun in Pujiang county, Zhejiang province, China) house F1 was a structure of 14 m long and 6 m wide, oriented along a north-west–south-east axis (Fig.31). There are three parallel rows of postholes, which are 27-50 cm in diameter and 70-90 cm in depth.

Fig.30: Hemudu houses wooden piles (http://www.whatsonningbo.com/travel-msg-638.html).

In each row, the distance between postholes is about 1.6 m, while the distance between rows is 3 m. Some of the postholes are constructed with small stones on the side or base (Jiang and Liu 2006; Zheng and Jiang 2007).

Fig.31: Remains of a pile dwelling at Shangshan (Jiang and Liu 2006).

Finally, I would like to mention the structures known as Crannogs. These peculiar buildings represents the classic type of prehistoric or early historic wetland settlement in Ireland (O'Sullivan 2009; 1998) and Scotland (Cavers 2010; Harding 2000; Henderson 1998), but also with at least one example in Wales (Campbell and Lane 1989). Linguistically, the word 'crannog' has a Gaelic derivation (from *crannóg* in Ireland and *crannag* in Scotland), and at its simplest it can be defined as an artificial or semi-artificial island. In Scotland over 350 crannogs sites has been discovered while in Ireland 1.200 (in excess) sites has been designated as crannogs. The earliest example of a largely (if not wholly) artificial islet is Eilean Dòmhnuill, on North Uist, is Scotland, dating to the Neolithic period, c. 3200–2800 BC (Armit 1996) (Fig.32). On the contrary, in the Neolithic Ireland, lake settlements does not appear to have been as extensive as in the later periods (O'Sullivan 1998). The crannogs could be constructed in two different ways:

- The Packwerk model that is an artificial mound built up consisting of layers of material upon which a structure, or structures, are built.
- A freestanding platform.

Both type have been registered in both the countries. However, when evidence for freestanding pile structures has been found in Scotland it has been located in areas immediately adjacent to, or surrounding (Fig.33). Some of the artificial Packwerk islets are the Coatbridge crannog in Lochend Loch, Asgog Loch in Argyll, Dhu Loch on Bute, and White Loch of Myrton in Dumfries and Galloway (Henderson *et al.* 2003; Cavers 2006). Even if for the moment the Packwerk mound should be regarded as the typical Scottish and Irish form, further surveys may reveal other freestanding structures. From the archaeological point of view the two different way of building create different taphonomic pathways, potentially altering how deposits are interpreted (Crone *et al.* 2001; Crone 2007; Cavers 2007). In a freestanding model a structure is placed on a platform above the water; this implies that all objects and structural elements, with the exception of the supporting piles, collapse and fall to become incorporated in the archaeological record.

Fig.32: Islet of Eilean Dòmhnuill (By Richard Law; http://www.geograph.org.uk/photo/2928636).

It is only with the Packwerk model that there is a realistic chance of discovering in situ occupation deposits, as in this model occupation surfaces are on or part of the makeup of the supporting mound (Henderson and Sands 2013).

Fig.33: Reconstruction of the Crannog at Kenmore (By Christine Westerback; http://www.geograph.org.uk/photo/35551).

2.5. BRONZE AGE PILE DWELLING

The site of Ürschhausen-Horn on Lake Nussbaum (Switzerland) presents two construction phase: the first, in Late Bronze, between 870 and 850 BC with occupation of varying intensity until around 800 BC (Gollnisch-Moos 1999; Hasenfratz and Schnyder 1998; Nagy 1999) and the second occupation phase of the site during the Iron Age, between the c. 663 and 638 BC (Billamboz and Gollnisch 1998; Gollnisch-Moos 1999). The Late Bronze Age settlement shows a mixture of building techniques utilized to construct rectangular buildings of 10 to 25 m^2. Individual buildings were constructed using either the *Schwellenabu* technique or *Blockbau* construction. Different type of flooring has been also found: from loam floors being laid directly on the ground with surrounding timber lintels, to cross and framing-work timbers being placed within the surrounding lintel structure to provide extra support for the floor.

***Schwellenabu* technique** (sleeper beam construction): piles are driven into the ground through planks or planks (Benkert *et al.* 1998; Gross *et al.* 1987; Seifert 1996). These planks not only provided stabilization and support for the building posts, but also formed the base and foundation of walls.

***Blockbau* technique**: known also as block construction method. It consists of layering round timbers on top of each other, intersecting and overlapping at building corners with notches/recesses to allow timbers to sit flush against each building (Menotti 2012).

The most elaborate foundation system involved the raising of buildings on platforms constructed in a simple *blockbau* technique with the insertion of the floor timbers at an intermediary level of the structure (Gollnisch-Moss 1999). The evidences related to the early Iron Age are scarce but but is clear that the new timber costruction were laid (Amt für Archäologie Thurgau 2010). The settlement sequence of the site proposed by Gollnisch-Moss (1999) provide an interesting account of the development of this Late Bronze Age village. Initial buildings appear to spread over the settlement area, while further construction events fill in the gaps, though there appear to remain two fairly distinct areas of the settlement - a more dispersed area in the north, and a more compact, dense, semi-regularized area to the south. An undeveloped space to the centre-west of the village may have been used as communal area. No palisade was found around the village, but apparent high-water barriers were observed in areas around the settlement, suggesting that some preparation were taken to protect against inundation (Menotti *et al.* 2014).

The Late Bronze Age settlement of Greifensee-Böschen on Lake Greifen (Switzerland) was occupied between the 1051 and 1042 BC (Eberschweiler *et al*. 2007). Construction of the settlement began with the first structures in 1051 BC, before a complete row of houses was finished around 1049/1048 BC.

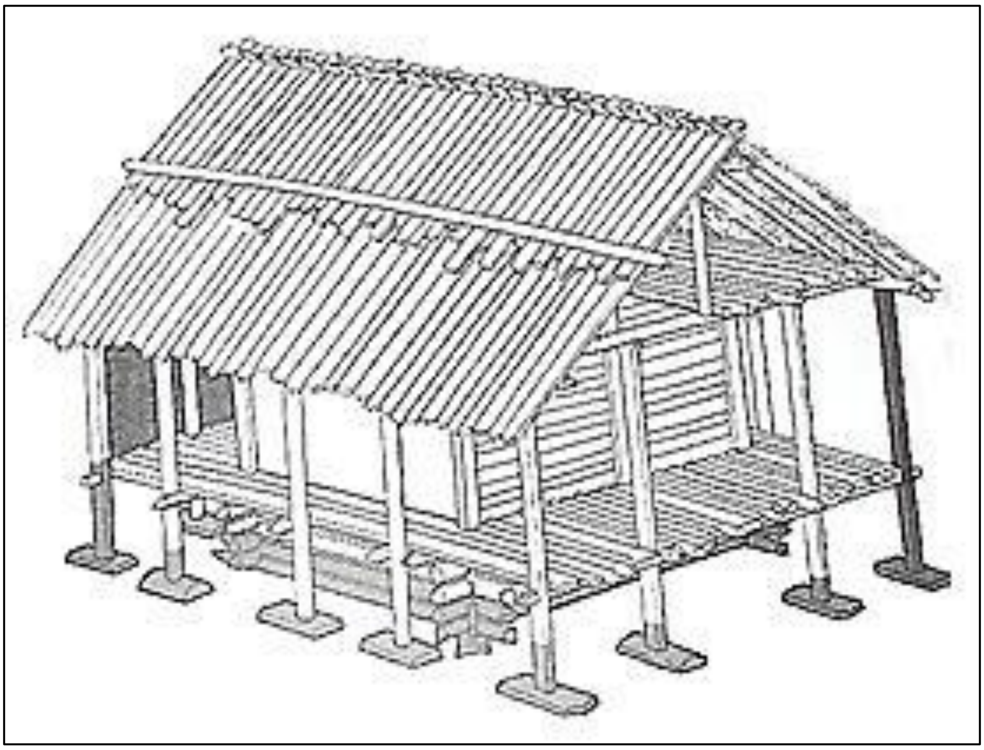


Fig.34: Schematic reconstruction of the Late Bronze Age house of Greinfesee-Böschen, Greifen lake Switzerland (Menotti 2012).

The settlement was surrounded by a palisade and a "Hedgehog" like structure, built of piles driven into the ground at an angle on the landwards site of the settlement. This structure, built around 1047 BC (Eberschweiler *et al*. 2007), would have worked as both defensive measure and wind breaks. In the following year the village had a new expansion including some structures built outside the surrounding palisade but within the hedgehog structure. The structures were constructed in an elaborated *blockbau* technique (Eberschweiler 1990; Eberschweiler *et al.* 2007) and various degrees of stabilization methods were utilized to ensure that the timber structure could not move around (Fig.34). Firstly, timbers or beams were secured together at their overlapping ends with treenails or binding to limit the amount of lateral movement that could occur within the structure itself. Secondly, stabilization was provided by pinning the *blockbau* structure into place with alignment piles or pegs, reducing the potential for the entire construction to move. To reduce the possibility of the structure sinking into the ground the guiding piles were driven into the ground through pre-cut timber planks that acted as weight spreaders for above building structure, in some cases the bottom layer of logs were also bound to timber planks. Occasionally, wooden planks were placed under the perimeter of the whole *blockbau* structure or with cross planks running across the long edges of the structure, which would also have assisted with weight distribution, and is similar to the Schwellenbau technique described above (Jennings 2014).

Few information about the upper elements of the building structures has been recollected but, building platforms have been inferred from piles and pile plates positioned around the *blockbau* foundations. These piles would have provided support for a platform that extended beyond the edges of the foundation. The archaeologists suggest that single buildings were built on these platforms, though it is apparent that the earliest structures (buildings H and J) were built on a single large platform. Whether the settlement was permanently above the water is currently unknown but the measures taken to stabilize the *blockbau* structure and elevation of the building platform suggest that the buildings were constructed in shallow water (Eberschweiler *et al.* 2007).

At the Late Bronze (1009-1010 BC) site of Cortaillod-Est (Switzerland), the three-aisle construction type was adopted, with four rows of posts (two wall posts and two internal posts) supporting the roof of the building, which measured up to 15.5x6 m in width (Arnold 1990) (Fig.35).

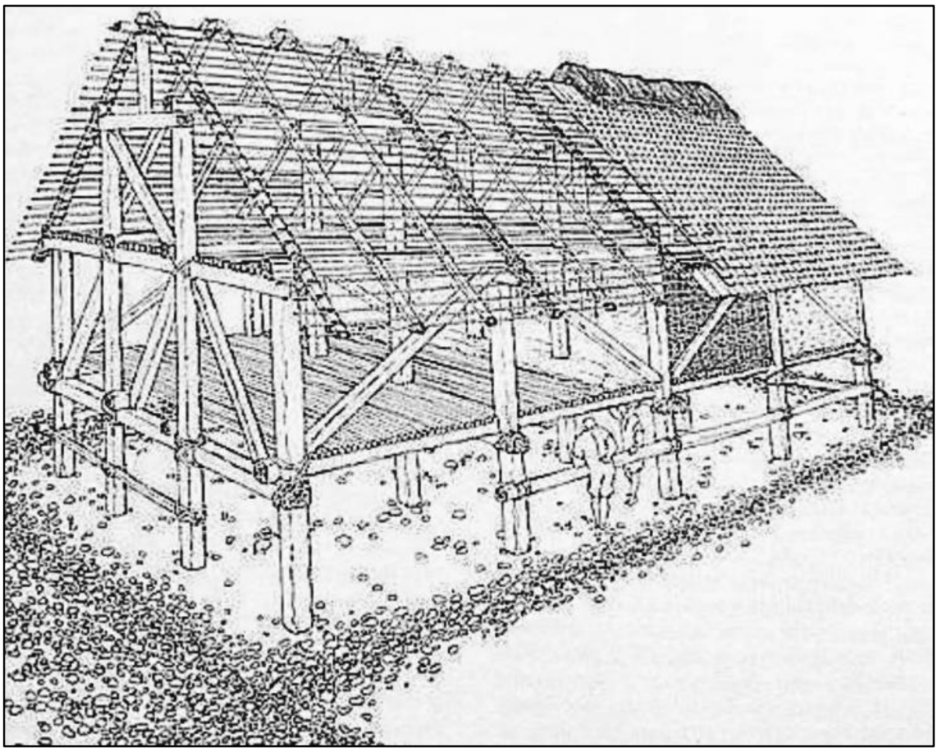


Fig.35: Reconstruction of house from Cortaillod-Est (Arnold 1990).

The Early Bronze Age pile dwelling village of Lavagnone (Brescia, Lombardy, Italia) consisted of the settlement and a passageway separated by a fence (De Marinis *et al.* 2004). Two pile dwelling settlements in stratigraphic continuity were identified in sector A: while the earlier dwellings (EBA IA) were dated dendrochronologically between 2070 and 1991 BC, the dendrochronological dates for the second settlement were 1984 and 1916 BC (Griggs, Kuniholm and Newton 2001; Carri 2014). The two structures were very similar, but did show differences As regardsss the architecture. While the EBA IA dwellings were simple post constructions, the posts of the dwellings dated to EBA IB rested on perforated wooden base plates (Fig.36). There was no evidence of the superstructures and perimeters of the individual houses, although some posts with pile points seemed to form rectangles. Research in sector B complemented this pattern. For easier access to the settlement area, a timber trackway was built starting from the northeastern edge. Finds and dendrochronological dates determined that the first construction work on the trackway was carried out 2070 BC; the fence, located in sector C, also dated from the same period and probably enclosed the village on its eastern side, where it was exposed towards dry land.

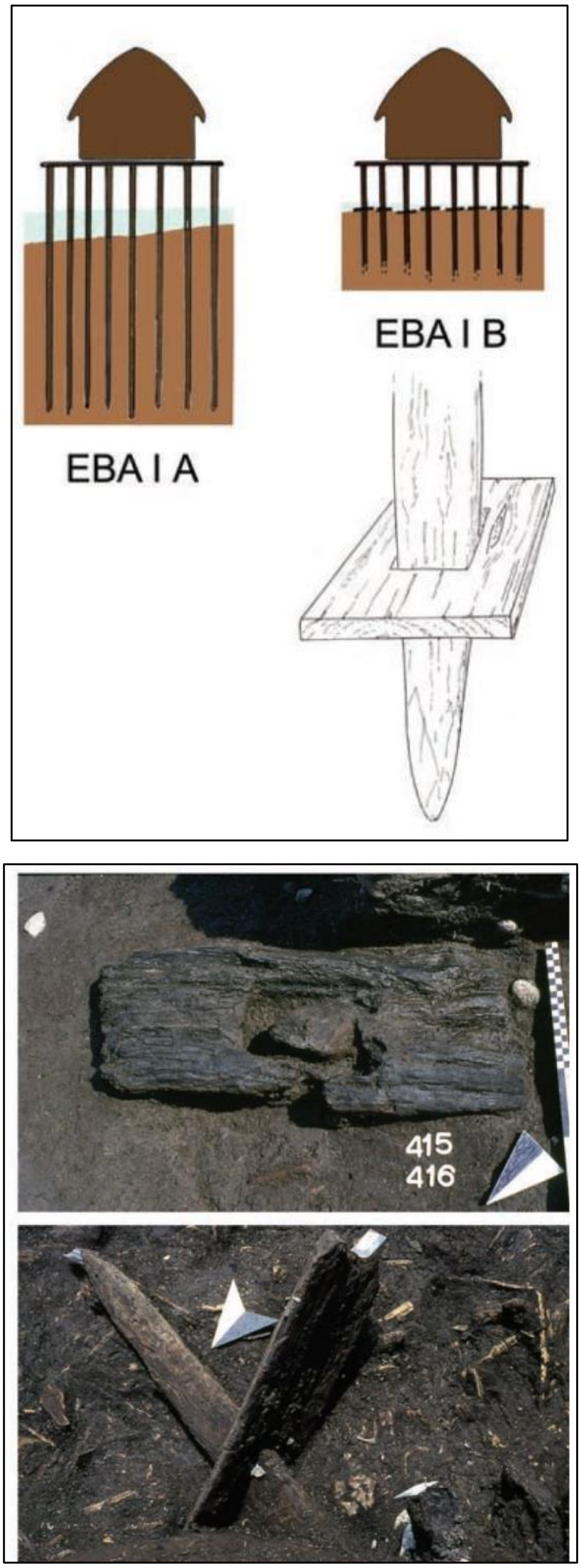


Fig.36. Top: Lavagnone EBA IA / IB pile dwelling schematic model. **Bottom**: Piles resting on perforated wooden base plates from sector A, Lavagnone (De Marinis *et al.* 2004).

The pile dwelling settlement of Stagno (Livorno, Tuscany, Italy) is dated to the final Bronze–early Iron Age (XII–XI century BC) (Giacchi *et al.* 2010). During the excavation, wooden structures were found in the grey organic clay banks, at about 3.5 m below the soil level, for a total extension of about 4500 m^2. The building technique is referable to a single construction model (Zanini 1997). In area C, the remains of the structure consist of seven vertical elements c. 120 cm long and c. 30 cm in diameter, with a long point (c. 50 cm) carved to facilitate insertion into the ground. Some of these vertical elements still preserved in situ the planks passing through rectangular openings in their upper part. Perpendicularly to these planks, spars of 350 cm maximum length and c.10 cm diameter were placed horizontally (Fig.37). Some small vertical piles were also found and are supposed to have functioned as further side support for horizontal elements. On the whole, the structure appears to have been well-anchored rectangular building with a peculiar level of small branches laid down in a compact manner (Fig.37), likely intended as a floor (Zanini 1997). A similar technique was employed in the Fiave`-Carrera settlement in Trentino, dated to the middle Bronze Age (in this case used for elevated huts) (Perini 1984).

Fig.37: Stagno: particular of the wooden relics of the pile dwelling settlement in the Area C (Zanini 1997).

A structure with horizontal spars and vertical anchoring piles, dated to the XIII–XII century BC, was identified in the lagoonal settlement of Caorle San Gaetano, near Venice (Bianchin Citton and Martinelli 2004).

The so-called "*Shaman's hut*", a Bronze Age (2200 c.a. BC) house from the pile dwelling village of the Lake of Ledro (Trentino Alto-Adige, Italy) (Battaglia 1943; Ghislanzoni 1955; Tomasi 1982; Baldo 1989; Magny *et al.* 2009), was composed of a platform on high piles on which lies the cabin (Fig.38).

Fig.38: The "Shaman's hut", Lake of Ledro (Trentino, Italy; www.stock.adobe.com).

It seems that the house had the lateral wall inclined creating the so-called A-Frame shape.

2.6. MODERN PILE DWELLINGS

Pile dwelling did not just vanished with the ancient eras. This particular way of settle is still used today in rally different parts of the world and it is interesting see how some form are very similar to the ancient one. The comparison between ancient and modern architectures is also useful to the process of reconstruction of the ancient building, helping to answer to those questions about particular architecture solution that the archaeological evidences could not answer (e.g. how was the roofing.). This is true especially for those modern areas were, especially because situation of extremely poverty, the houses are built using ancient techniques. This can be very useful at the moment of reconstructing the Neolithic pile dwelling giving us hints about how the ancient house could be constructed.

2.6.1. Iberian Peninsula - Portugal

The stilt-houses built by the waterside are one of the most ancient typologies of vernacular architecture in Portugal. Vitally linked to the rivers, they reflect a common building strategy, with common materials and methods that are perfectly matched with nature (Virtudes and Almeida 2012). Among these there are the houses of the Avieiras' villages of the Tagus River (*e.g.* Caneiras, Escaroupim, Palhota Patacão), built by the fishing community, coming from a place called Vieira de Leiria found on the Atlantic shore (Fig.39,40,41). These stilt-houses were built according to traditional techniques of construction using local materials such as wooden branches or cane. Nowadays, these stilt-houses are a unique legacy of the vernacular architecture linked with the rivers landscapes in Europe. The matrix of the "Avieira" houses if formed by:

- Wooden planks arranged vertically placed over on the floor built over the stilts which measured 200 meters tall;
- Wooden stilts or tree trunks;
- Exterior stairs provide the access directly to the entrance or to a covered balcony located on the facade where is located the entrance.

The interior usually consists of three divisions, living room and bedrooms whose communications are blocked by curtains. The wooden walls are painted or lined with coloured patterns paper; the fireplace is in the corner of the room, without the function of cooking because the kitchen is an outside annex; the bedrooms are symmetrical each with a small window and differently coloured (blue for boys and pink for girls).

Fig.39: “*Avieira*” houses on Tagus River (http://www.asfint.org).

The outer walls were painted with cheerful colours like green or red. These houses were entirely built of wood and sometimes appeared isolated, associated with a family; sometimes grouped in two or three buildings, associated with a family or with several family ties; sometimes in urban settlements with several buildings aligned.

Fig.40: “*Avieira*” houses on Tagus River: detail of a boardwalk (http://www.asfint.org).

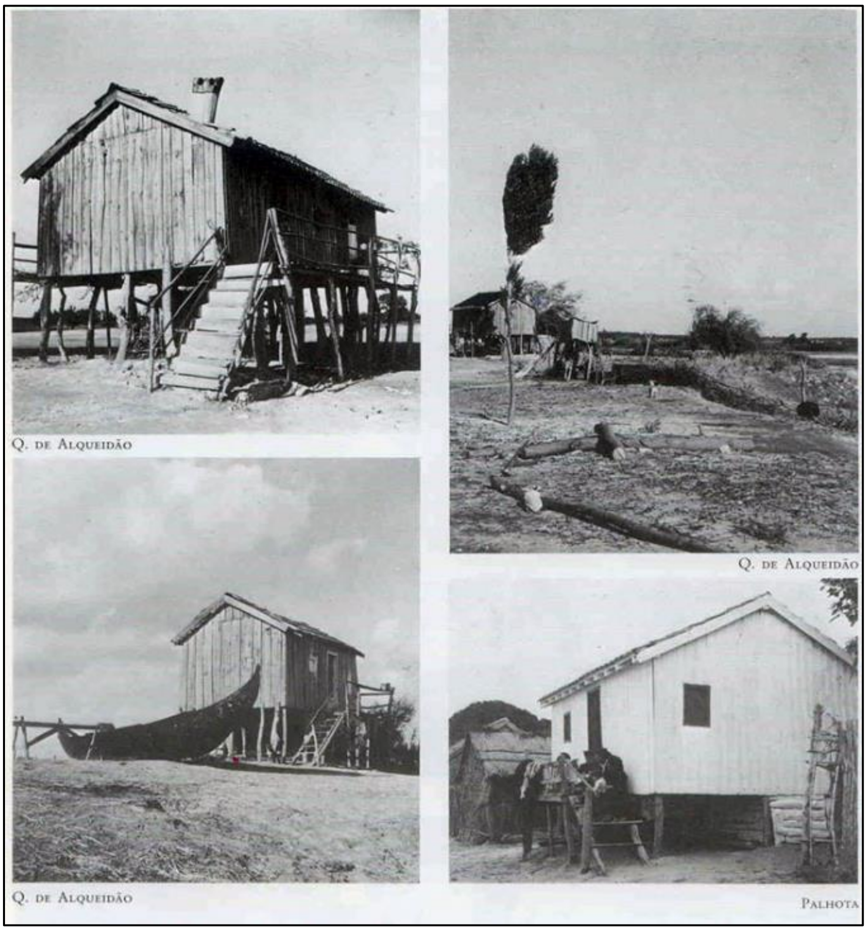


Fig.41: ‘*Avieira*’ house in "Arquitectura Popular em Portugal", edition of the Sindicato Nacional dos Arquitectos, Lisbon, 1961 (Virtudes and Almeida 2012).

2.6.2. Scandinavian Peninsula - Norway

Typical of the Norwegian landscape are the angler cabins or wharf. These pile-dwellings were built half on wooden piles driven in the sea bottom and half on the rocky coast. This structure allows handling goods directly from the boats. The wharfs could be one or two stories and contain rooms to store the fishing tools, goods etc. (Jakhelln 2014)

2.6.3. Asia - Philippines

Among the vernacular architecture of the Filipino houses, we can found the “Nipa house” (Fig.42,43). This simple type of pile dwelling are built using the *bayanihan* system were the entire community helps the family to build or move their home. In some cases, these houses are built following the ancient tradition, which means without the use of “modern” technologies: for example, when a Nipa house is built using local timbers as frames, mortise and tenon joints were sometimes used to join wooden members together instead of using nails (Fig.44). In the lowland, were the most common building material is the bamboo, rope lashings made from rattan or *yantok* (woven split bamboo mats) were used to join the wooden frames together. The wooden frames consisted of posts, beams, floor joists, rafters for the roof, and horizontal and vertical studs to support the wall panels, which were made from either *sawali*, bamboo, or coconut leaves. High-pitched roofs were often used to counter heat and rain and allow for better air circulation inside the house (Klassen 1986; Dacanay 1992; Hila 1992).

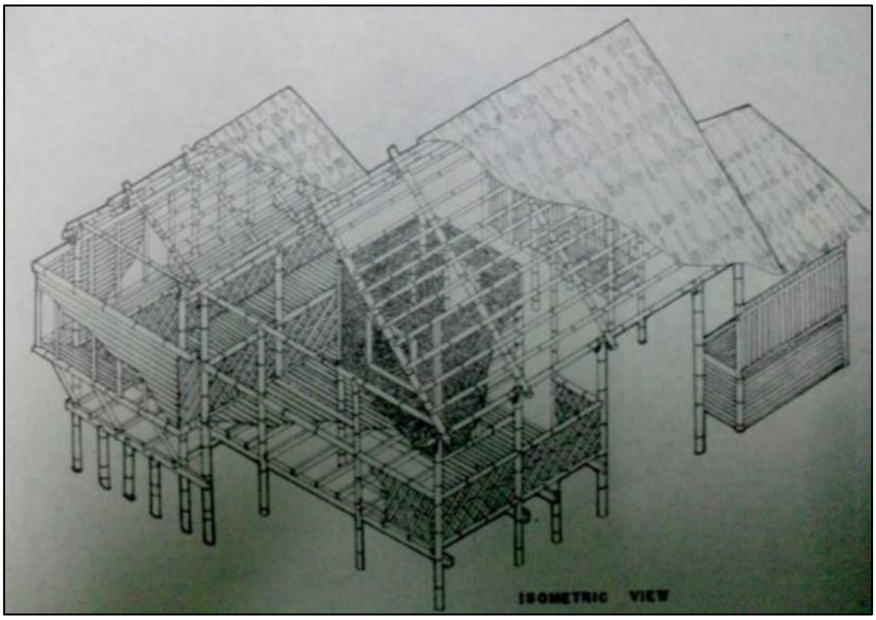


Fig.42: Lowland Nipa house predominantly made of bamboo (Sales 2013).

Fig.43: Example of Nipa house (https://martinsazon.wordpress.com/category/hstarc4/).

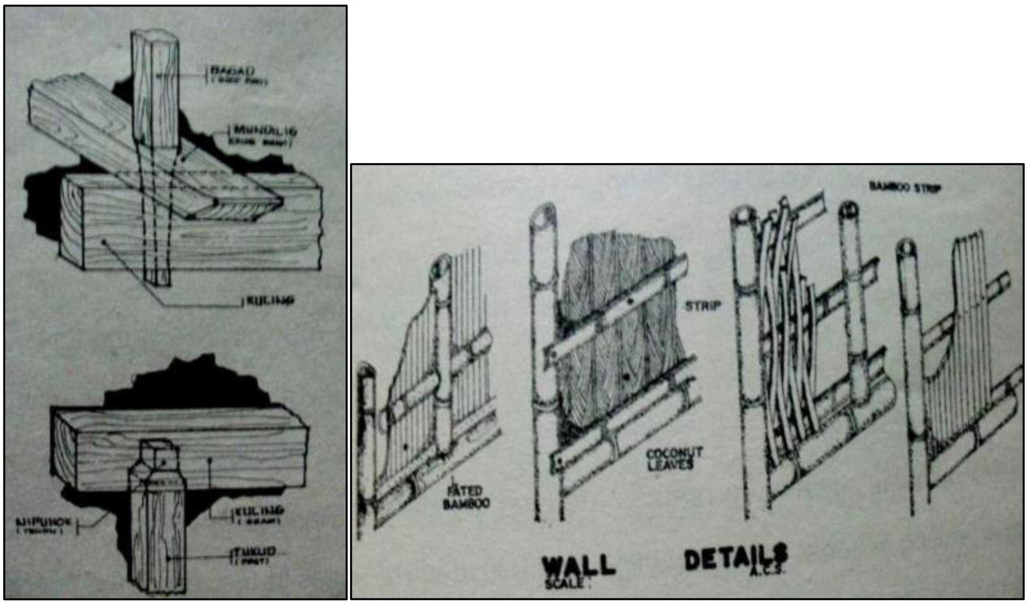


Fig.44. Left: Mortise and tenon joint used in Nipa huts in the Cordillera region (Sales 2013). **Right**: Examples of different types of materials used for walls in a bamboo Nipa hut (Sales 2013).

In the Sulu Archipelago, the pile dwelling is also the way of life choose by the different ethnic groups (like the Badjao and the Samal) that live there. The houses are made of bamboo and palm. Bamboo piles held small platforms, always made of bamboo piles, on which small houses are built. The structure of the house is made of bamboo while the roofing and the wall are made of palm's branches. In other cases, like the Samal of eastern Sulu Archipelago, bamboo can be replaced by wood. Houses consist of one or more small rectangular rooms and an attached kitchen, all on the same level. The houses are clustered together, connected by catwalks of timber, and split bamboo (Gowing 1979).

2.6.4. Asia - Myanmar

At Nampan village on Lake Inle it is possible to observe another example of "modern" pile dwellings. As in the precedent cases, the houses are made of bamboo, wood and palm branch.

2.6.5. Asia – Malaysia

The traditional Malay settlement, or "*kampong*", it is forms by several households and is led by a headman. The construction elements in Malay vernacular architecture are light timber-framed structures, forming elevated floors, sloping long roofs with large overhangs, louvered windows, timber or woven bamboo walls and screenings (on the upper walls). In terms of spatial elements, the basic spaces of the *serambi, rumah ibu* and *dapur* are the most common in a traditional Malay house (Fig.45,46). The *serambi* is a sort of porch, completely o partially walled, situated in front of the house and it is the smallest space of the house (Sahabuddin and Longo 2015).

Elements	Activities	Privacy Level
Serambi / Anjung (Veranda / Porch)	Male entrance, relaxing, child monitoring, greet and treat space for guests	Public space
Rumah ibu (The main/core of the house)	Meeting, praying, reading / reciting, sleeping (at night)	Semi private and private space
Selang / Pelantar	Female entrance, chitchatting	Semi private space
Dapur (The kitchen of the house)	Cooking, preparing foods, dining, washing	Private space
Kolong (Space underneath the house)	Storing, working, repairing, drying clothes	Public space

Fig.45: The uses and privacy level of internal spaces in traditional Malay House (Yuan 1987).

Its function is to serve as the first greeting space for guests after entering the house (Yuan 1987; 2001). The *rumah ibu* is the core space of the Malay house. This has the largest area, highest floor level and highest roof level (Yuan, 1987). Lighting in this space is reduced to provide coolness. (Yuan 1987). Usually this space is used for official events but also as space of relax, mingling with the family members and as sleeping area during the night (Chen *et al.* 2008). The *dapur* is the kitchen and it is always located on the back of the house (Yuan, 1987). The functions of this space are for cooking, washing and eating. The usual building material include wood, bamboo and palm leaves usually taken directly from nearby forests (Yuan 1987).

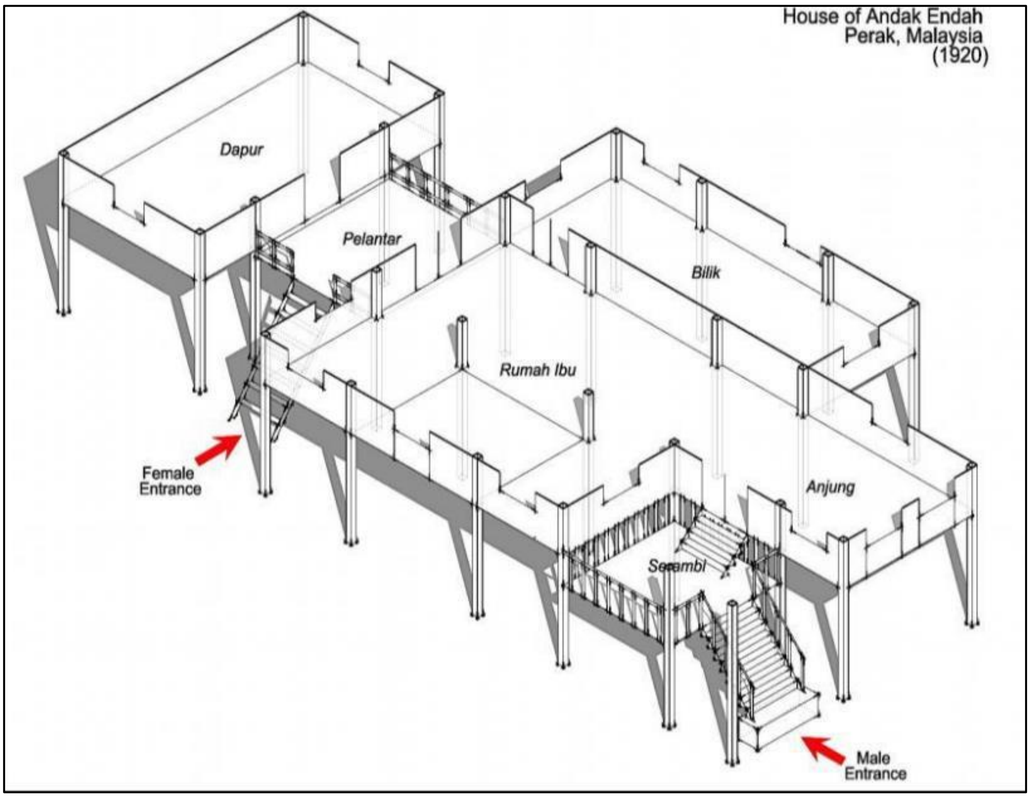


Fig.46: The internal layout of Andak Endah House, 1920 (Sahabuddin and Longo 2015).

Figure 47 show how different materials are used to build the different parts of the house. The palm is often used as roof covering due to the fact that releases the heat readily; however, it does not last as long as the other materials so has to be changed frequently.

Construction Parts	Types of Wood
Structural (Columns, Beams, Joists, Girts)	*Cengal, Merbau, Damar Laut* and *Petaling*
Non-Structural (Walls, Windows, Doors)	*Meranti* and Bamboo
Roof (Roof Finishes)	*Nipah, Rumbia, Bertam* and *Kabong*

Fig.47: Types of wood used in a Malay House (Yuan 1987).

As a lightweight timber structure, a traditional Malay house regularly uses posts and a lintel timber structure (Fig.48).

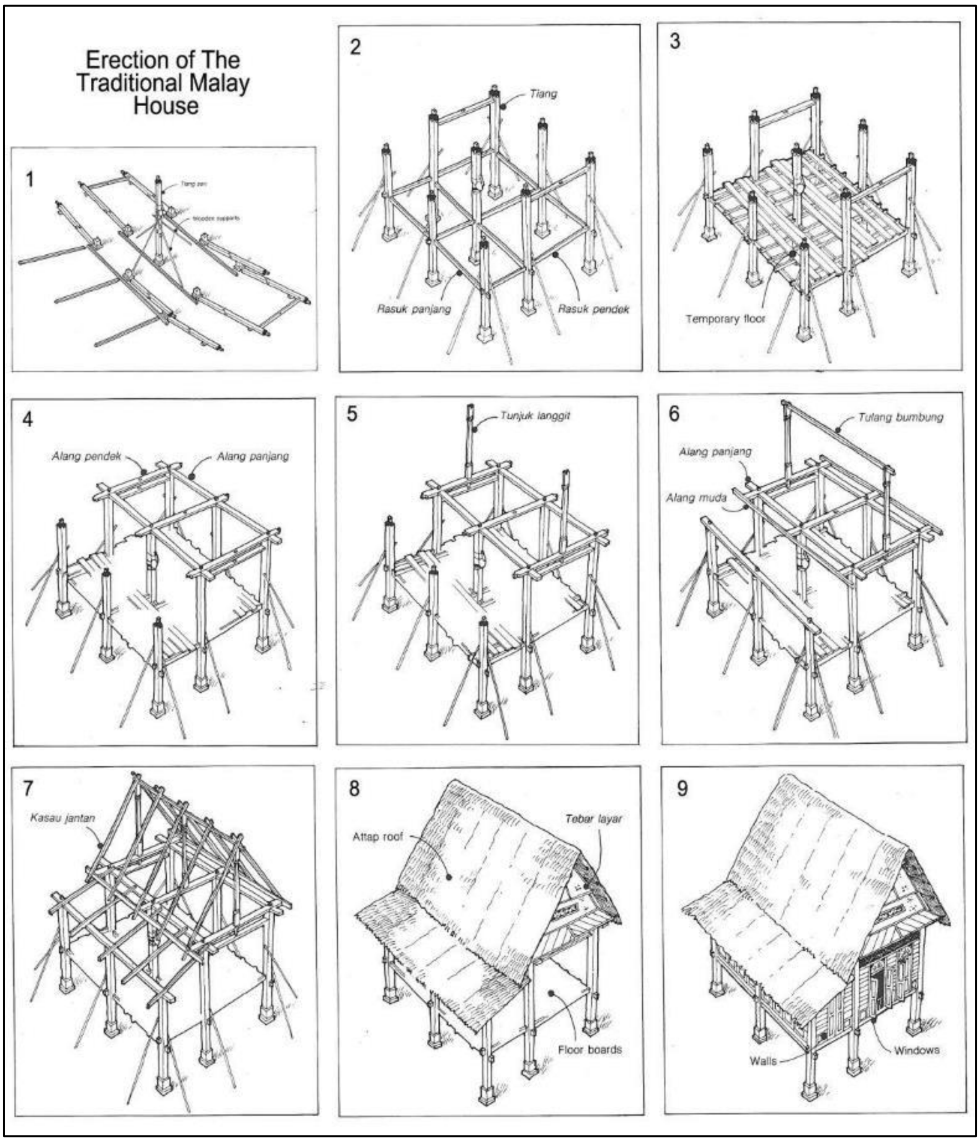


Fig.48: The erection of basic traditional Malay house form (Yuan 1987).

The posts rest on concrete or stone footings without any foundation required (Yuan 1987). The structural framework for the house consists of posts braced by floor joists and roof girders. The non-structural components are windows and panels for the floors, walls, stairs and roofs fitted between the frames. The floor is nailed on the floor joist, and it is also common to leave gaps between the planks to facilitate activities of cleaning (sweeping and washing) or for religious needs (bathing the family member's deceased).

As said before, the traditional Malay settlement is known as "*kampong*" (Fig.49). The internal arrangement of the traditional *kampong* could be:

- Linear: the houses face the economic resources and transportation links such as roads, rivers or beaches (Tjahjono 2003).
- Concentric: the *serambi* usually faces the public space located at the centre of the houses (Tjahjono 2003).

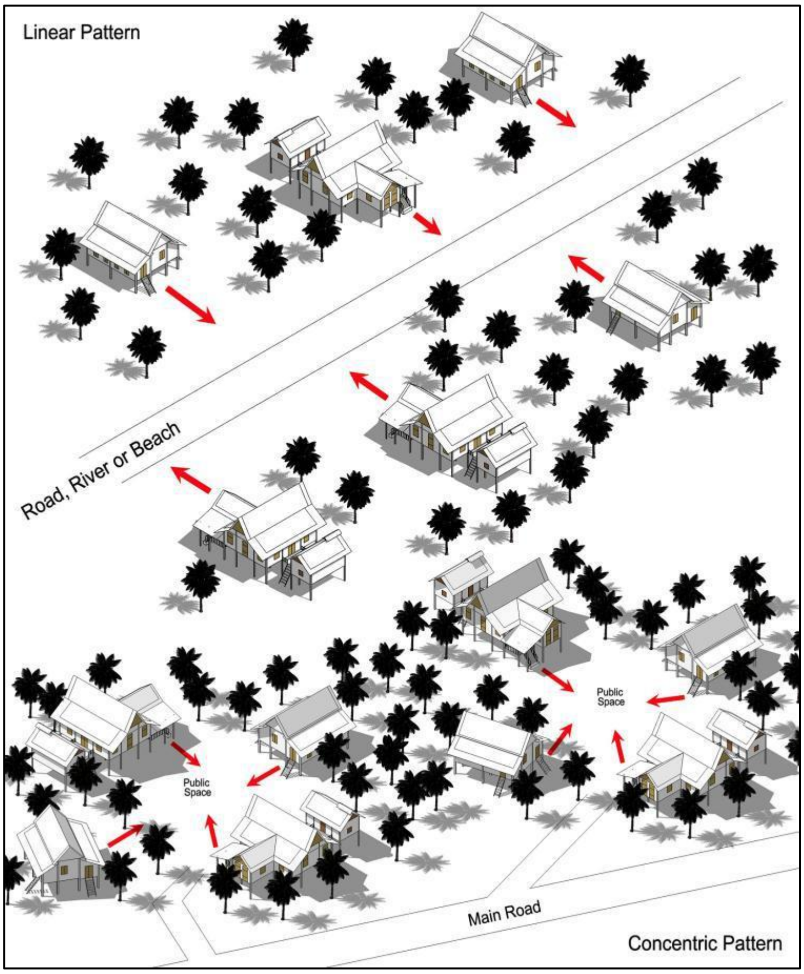


Fig.49: Linear and Concentric Patterns of Traditional Malay "*Kampong*" (Sahabuddin 2015).

In both cases, the houses are detached and dispersed with ample external spaces between them to allow fresh air circulation (Hanafi 1994) (Fig.50). The houses are built on piles, an approach that has several benefits from a thermal, functional and safety point of view. The raised floor, which is built higher than the ground, can catch winds of a higher velocity (Yuan 1987), and the use of timber planks for the floor, which have gaps between them, can bring the air to the inner space. Hanafi (1994) suggests that moist ground requires more sunlight to dry, and a raised floor is one of the solutions. The elevated floor also helps in case of floods. Several research findings about stilt heights in traditional Malay houses have proved those in the northern region have more height than those in the southern region. A traditional Malay house allows ventilation by having many full-length windows and doors at body level (Yuan 1987). Such large openings the house walls create high air intakes outside to reduce the performance of the stack effect.

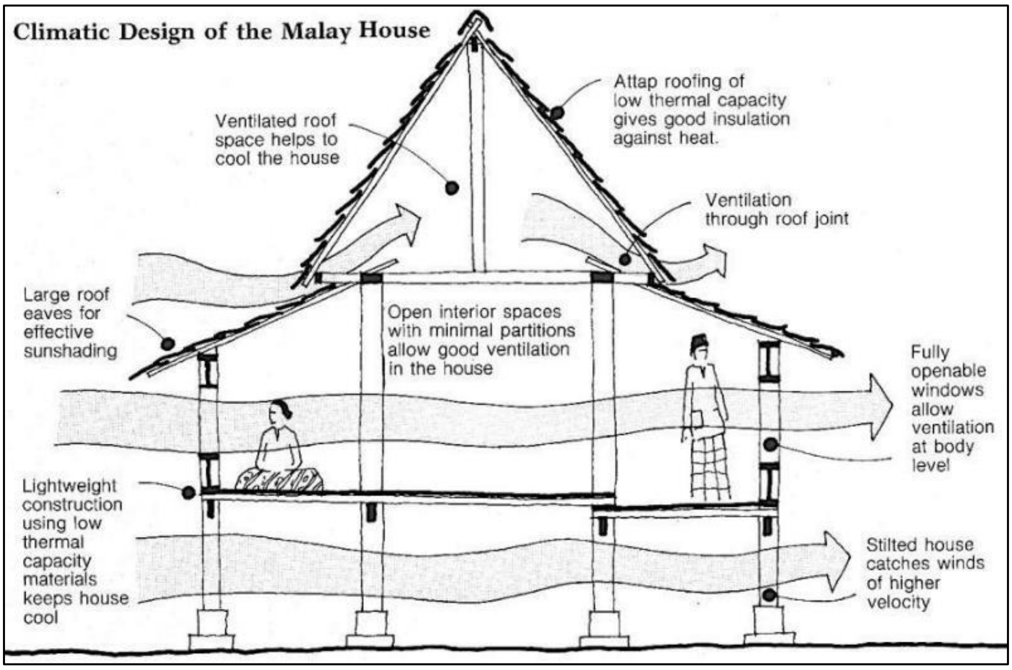


Fig.50: Climatic Design of Malay House (Yuan 1987).

As already saw in Myanmar and Philippines in Malaysia pile dwelling on water is diffuses like at Sabah (on the Borneo Island) where is possible to encounter villages composed by wooden pile dwellings.

2.7. ARCHITECTURAL ANALYSIS, DISECTING A SIMPLE TIMBER HOUSE: House Architectonic Basic Elements

The next step of the research has been to analyse the building elements of La Draga in respect to the basic planes composing a house in order to find a location to all the architectural wooden elements found so far. For this reason a description of architectural elements, which have been considered for this analysis, are summarized here. The main architectural element of the house is what the theory of architecture identify as plane (Pramar 1973; Ching 2014). When a line is extended in a direction other than its intrinsic direction, it becomes a plane. While the line has just one dimension, the plane has length, width and shape is the primary identifying characteristic of a plane. Its shape is determined by the contour of the line forming the edges of a plane. A plane extended in a direction other than its intrinsic direction becomes a volume. In the composition of a visual construction, a plane serves to define the limits or boundaries of a volume. Planes in architecture define three-dimensional volumes of mass and space. A plane could be horizontal or vertical. Architecture works mainly with three generic types of planes: overhead plane, elevated plane, base plane and linear elements, and relationships between them (Pramar 1973; Ching 2014). We can individuate three architectural planes (Fig.51):

- Base plane
- Elevated/vertical plane
- Overhead plane

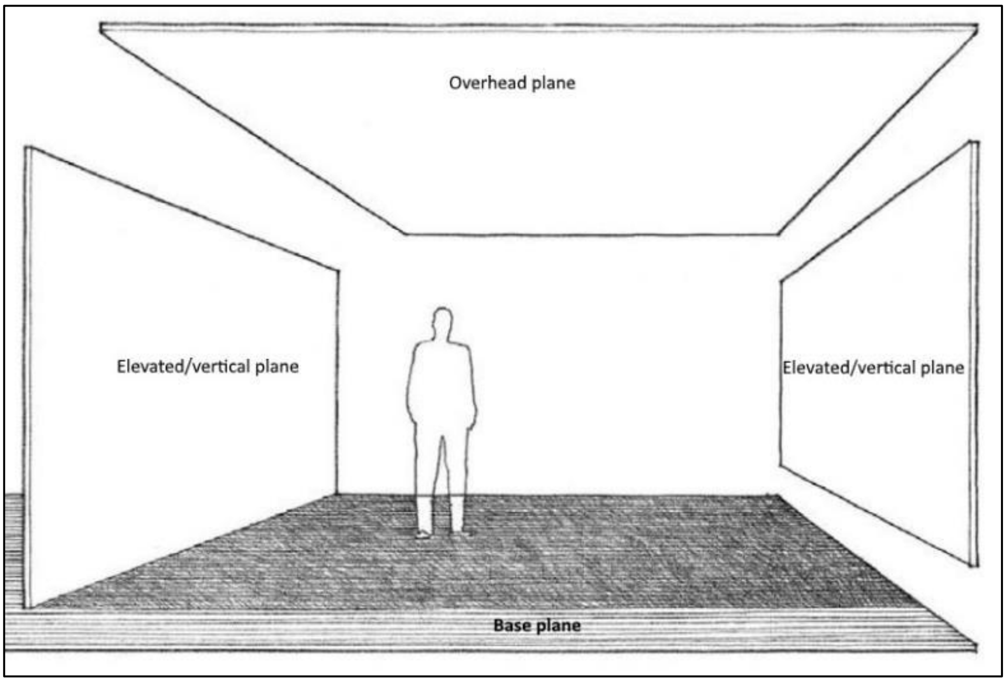


Fig.51: The different planes of a building (Ching 2007).

To these three architectural planes, we have to add:

Linear Elements

Elements that, like columns and beams (Fig.52), possess the necessary material strength to perform structural function. They can provide support for an overhead plane, form a three-dimensional structural frame for architectural space and express movement across space. At a smaller scale, lines articulate the edges and surfaces of planes and volumes. These lines can be expressed by joints within or between building materials, by frames around window or door openings, or by a structural framing of columns and beams. Row of linear elements could be used to support the floor or roof plane above. How these linear elements affect the texture of a surface will depend on their visual weight, spacing, and direction (Pramar 1973; Ching 2014).

Fig.52: Columns are a prime **e**xample of linear elements (http://www.sashco.com).

<u>Openings</u>

All that elements that “open” a surface plane interrupting its continuity (Fig.53). Openings can determine patterns of movements (doors) and/or allow light to penetrate the space (windows) and illuminate/ventilate a room. They can offer views from the interior to the exterior and vice versa and establish visual relationship between rooms and adjacent spaces. Finally, depending on size, number and location, they can weaken the structure (Pramar 1973; Ching 2014).

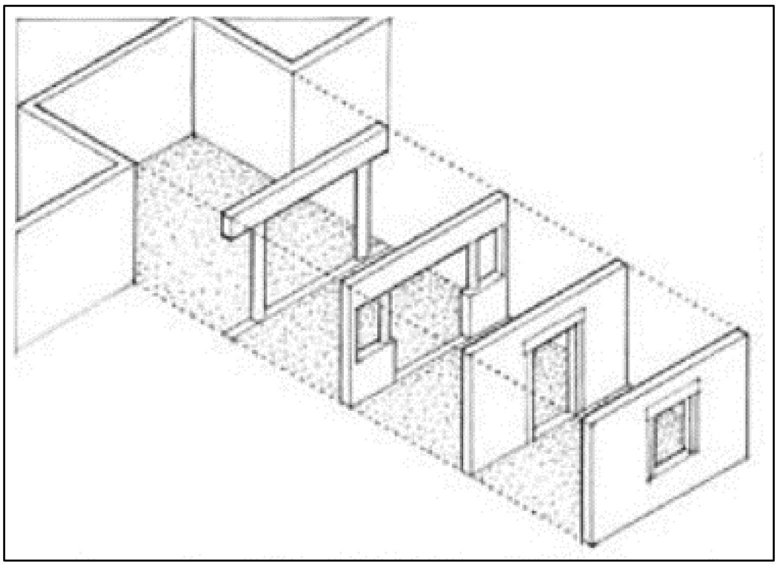


Fig.53: Different types of openings (Ching 2007).

Connections

Implies the method with whom the different elements of a plane are tied together: mortar, ropes, nails etc. (Pramar 1973; Ching 2014).

2.7.1. Simple Timber House's Parts

Using the terminology coming from the timber house architecture we can named the different parts of the cabin model (Fig.54):

RIDGE PLANK/RIDGE BEAM: a longitudinal member at the apex of a roof, which supports the upper ends of the rafters. Also-called a ridge beam, ridge piece, ridge plate, or ridge tree.

(COMMON) PURLINS: in timber-framed construction, one of a number of horizontal timbers that are parallel to the ridge of the roof, and joined to the principal rafters into which they are seated.

PRINCIPAL PURLIN: principal purlin in timber-framed construction, a purlin that is somewhat heavier than a common purlin; usually runs parallel to the ridge of the roof about halfway between the ridge and the top plate. The only purlin on each side of the roof ridge, it is framed into and joins the principal rafters, thus providing lateral stability for the entire roof framing system and support for a number of common rafters.

(COMMON) RAFTERS: one of a series of inclined structural members from the ridge of the roof down to the eaves, providing support for the covering of a roof.

PRINCIPAL RAFTERS: principal rafter in a timber-framed house, one of several such rafters that extend from the ridge of the roof down to the wall plate; somewhat heavier than a common rafter; often located at a corner post, story post, or chimney post and framed into a tie beam. Principal rafters, together with the principal purlins, form a roof framing system having considerable stability. Also-called a blade.

ROOF PITCH: the slope of a roof, usually expressed as the angle of pitch in degrees or as a ratio of vertical rise to the horizontal run.

TIE BEAM: a horizontal timber connecting two opposite rafters at their lower ends to prevent them from spreading.

JOIST: one of a series of parallel beams of timber used to support floor and ceiling loads, and supported in turn by larger beams, girders, or bearing walls (Fig.55).

WALL PLATE: on horizontal member (such as a timber) across a timber-framed, masonry, or concrete wall to carry and distribute the load imposed by members that support the roof.

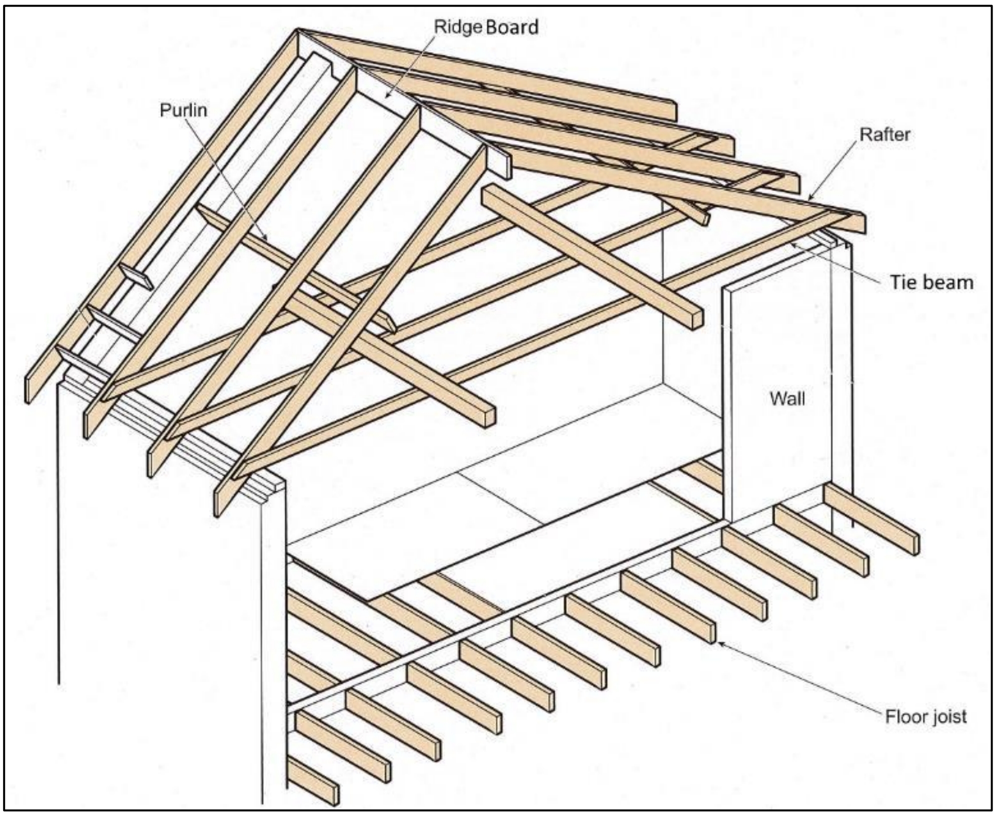


Fig.54: House elements (http://kingmoorconsulting.co.uk).

PILE: a concrete, steel, or wood column, usually less than 60 cm in diameter, which is driven or otherwise introduced into the soil, usually to carry a vertical load or to provide lateral support.

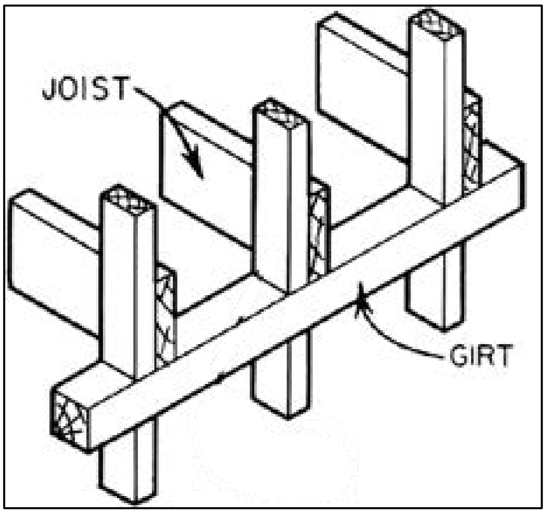


Fig.55: Relation between joists and girts in a timber house (http://encyclopedia2.thefreedictionary.com).

2.7.2. Base Plane

The base plane can be either the ground plane that serves as the physical foundation and visual base for building forms or the floor plane that forms the lower enclosing surface of a room (Pramar 1973; Ching 2014). The ground plane ultimately supports all architectural construction. Along with climate and other environmental conditions of a site, the topographical character of the ground plane influences the form of the building that rises from it. The building can merge with the ground plane, rest firmly on it, be elevated above it or depressed. The floor plane is the horizontal element that sustains the force of gravity as we move around and place objects for our use on it. It may be a durable covering of the ground plane or a more artificial, elevated plane spanning the space between its supports. Like the ground plane, the form of a floor plane can be stepped or terraced to break the scale of a space down to human dimensions and create platforms for sitting, viewing, or performing. It can be elevated to define a sacred or honorific place.

Components of a Base Plane

In a timber house, the base plane could be simple, made of the soil itself or a layer of a particular material, or complex implying a structure consisting of elements like girts, posts, joists and plates forming a structure meant to hold the material composing the floor.

2.7.3. Vertical Plane

Vertical elements also play important roles in the construction of architectural forms and spaces. They serve as structural supports for the roof/overhead planes. There are vertical linear elements, like the columns, and vertical planes, usually identified with the walls. Exterior wall planes isolate a portion of space to create a controlled interior environment. Their construction provides both privacy and protection from the climatic elements for the interior spaces of a building, while openings within or between their boundaries re-establish a connection with the exterior environment.

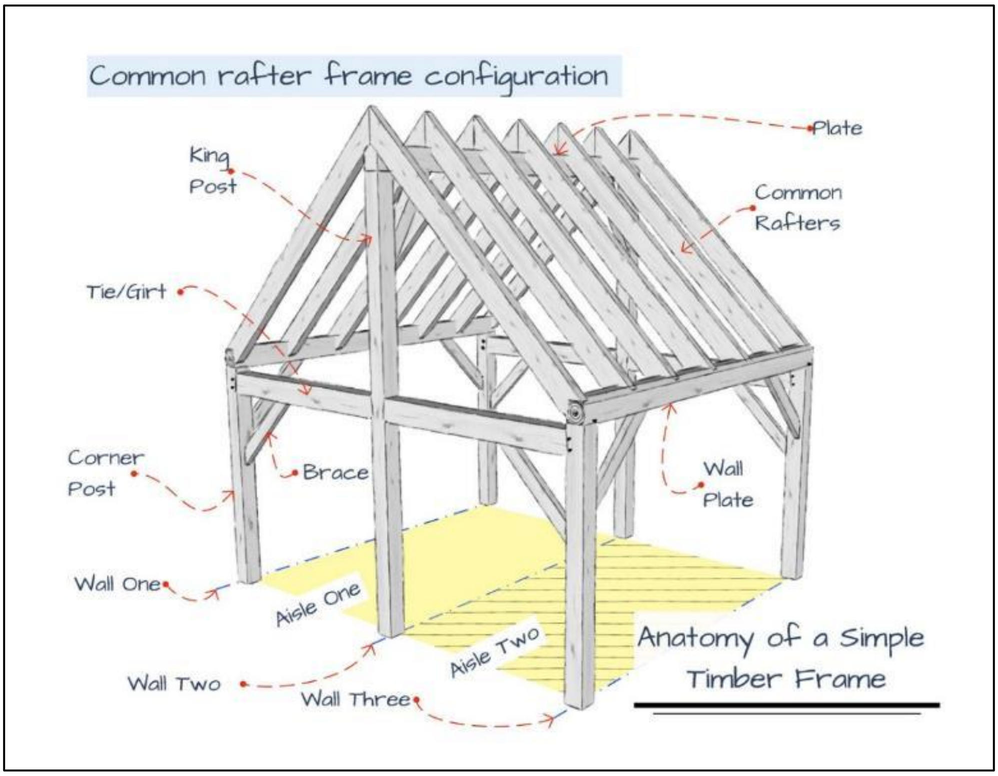


Fig.56: Simple timber frame (http://www.timberframediy.com).

As exterior walls meld interior space, they simultaneously shape exterior space and describe the form, massing, and image of a building in space. Interior wall planes govern the size and shape of the internal spaces or rooms within a building. A vertical plan has two opposed surfaces or faces, which establish two distinct spatial fields. These two faces can differ in form, colour or texture to articulate different spatial conditions. The height of the vertical plane relative to our body height and eye level is the critical factor that effects the ability of the plane to describe, visually, spaces giving, for examples, different sense of enclosure. As a design element, a wall plane can merge with the floor or ceiling plane, or be articulated as an element isolated from adjacent planes. It can be treated as a passive or receding backdrop for other elements in the space, or it can assert itself as a visually active element within a room by virtue of its form, colour, texture, or material. A compelling way to use the vertical wall plane is as a supporting element in the bearing- wall structural system. While walls provide privacy for interior spaces and serve as barriers that limit our movement, doorways and windows re-establish continuity with neighbouring spaces and allow the passage of light, heat, and sound (Pramar 1973; Ching 2014).

Components of a Vertical Plane

In a simple timber house (Fig.56), the vertical plane consists of corner/principal posts, tie beams to link them, two wall plates lying on the corner posts and meant to hold the rafters and eight braces, who connect the corner posts with the tie beam and the wall plates for stability. All these elements compose the framing for the material composing the walls per se like woods, stones or bricks.

2.7.4. Overhead Plane

The overhead plane main role it is to offer protection. It can be either the roof plane that shelters the interior spaces of a building from the climatic elements, or the ceiling plane that forms the upper enclosing surface of a room. The material, geometry, and proportions of its structural system and the manner in which it transfers its loads across space to its supports, in turn, determine the form of the roof plane. The overhead plane can visually express how the pattern of structural members resolves forces. The roof plane can be hidden from view by the exterior walls of a building or merge with the walls to emphasize the volume of the building mass. It can be expressed as a single sheltering form that encompasses a variety of spaces beneath its canopy, or comprise a number of hats that articulate a series of spaces within a single building. Finally, the overhead plane can be the major space-defining element of a building and visually organize a series of forms and spaces beneath its sheltering canopy. The ceiling plane of an interior space can reflect the form of the structural system supporting the overhead floor or roof plane. Since it need not resist any weathering forces nor carry any major loads, the ceiling plane can also be detached from the floor or roof plane and become a visually active element in a space (Pramar 1973; Ching 2014). As said before, the overhead plane can be either the roof or the ceiling.

Roof plane:

- Can be single or multiple.
- Can extend outwards as overhang.
- Can be elevated to allow breeze to pass through.

Ceiling plane:

- Can reflect the form of the structural system.
- Can be detached from the roof plane, suspended, underside of an overhead. Can be lowered/raised to articulate spaces.
- Can be manipulate to define and articulated spaces.
- Can be manipulated to define and articulate zone of spaces.

Components of an Overhead Plane

The overhead plane of a simple timber house (Fig.57) is generally composed of one ridge beam, several purlins, rafters, and two tie beams. Usually, among the purlins and the rafters, there are two principal purlins and four principal rafters: heavier than the others, they play an important role for the stability of the roof. The interconnection of all these elements forms the roof framing meant to support the covering on both the roof pitches (Pramar 1973; Ching 2014).

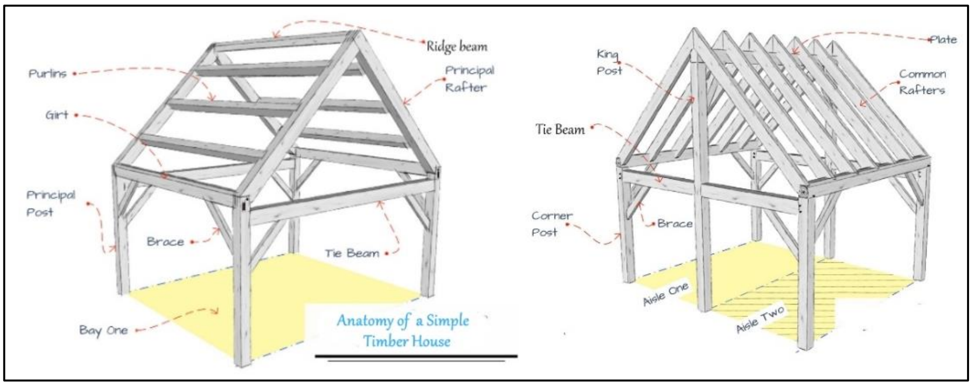


Fig.57: Anatomy of a simple timber house (http://www.timberframediy.com).

2.8. CREATING A GENERIC DESCRIPTIVE MODEL

In order to describe the general function of these elements we establish the following definitions (Fig.58):

- **Mono-Functional/Multi-Functional:** in order to describe if an element has a single or more function i.e. a wall could act just like a wall or being wall and roof at the same time.
- **Homogeneous/Heterogeneous:** means that a house's element it is made of one or more materials, i.e. a wall could be made of one single slab of stone or of wood and stone together.
- **Natural/Artificial:** if an element, it has been created or taken from the environment. Among the natural ones we differentiate between natural element used as they are found (without modifications) and natural element that had been modified.

Overhead plane: could be Mono-functional or multi-functional, homogeneous or heterogeneous, artificial or natural.

Elevated plane: could be Mono-functional or multi-functional. In both cases a wall could be natural or artificial and both homogeneous or heterogeneous.

Base plane: could be artificial (foundation) or natural (soil). If is artificial it could be lowered or elevated. If the base is natural, it could be worked or not worked. In this group, we find also soil use like floor and could be artificial or naturals, homogeneous or heterogeneous. If a floor is made of natural soil not worked it falls inside the natural bases group.

Linear elements: could be artificial or natural. If they are artificial could be homogeneous or heterogeneous. If they are natural, they could be worked or not worked.

Openings: could be natural or artificial and either built or obtained from an existing surface (like making a hole inside a wall).

Connections: could be artificial or natural and homogeneous or heterogeneous.

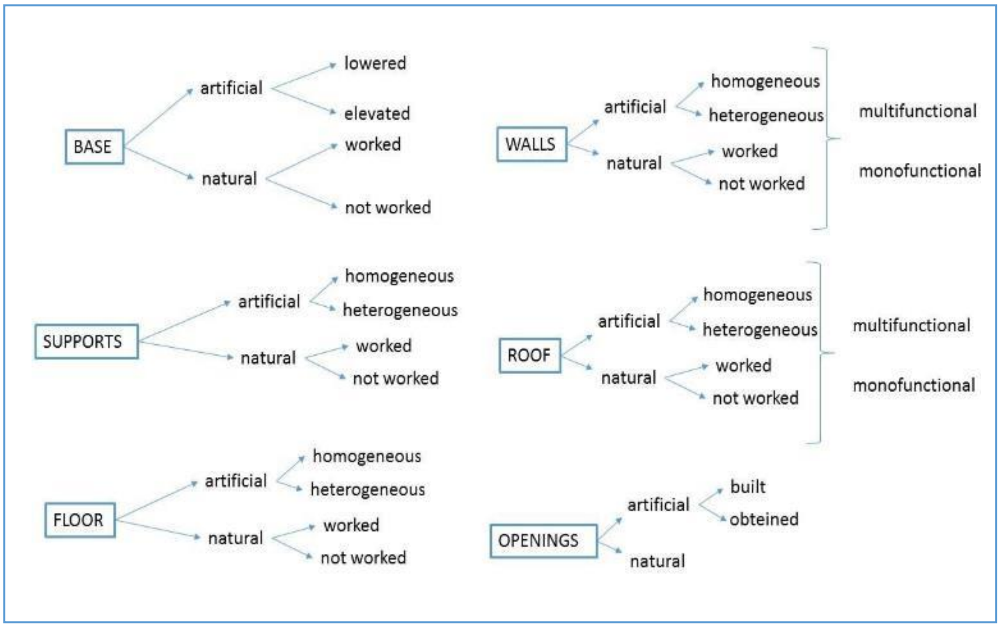


Fig.58: House's key elements and their general characteristics.

2.9 THE PHYSICS BEHIND PILE DWELING ARCHITECTURE - *Foreword*

The following section is focused on the physical forces to which a pile dwelling is subject. Even if these studies come out from analysis taken on modern pile dwellings in Holland (Murris 2011) the forces at work does not change, they are universal. These studies will be also very useful in the future when we will test our model, in order to observe its reactions under such forces.

2.9.1. Foundation Structure

Among the different planes that compose a building, the base plane is probably the most important one as part designed, usually, to hold the entire structure. For this reason the base plane is generally identify with the foundations of a structure. As with other types of foundations, the purpose of a pile foundation is to transmit a foundation/structure load to a solid ground and to resist vertical, lateral and uplift load (Abebe and Smith 2005). As for the others elements of the house, also the nature of the base plane depends on different factors like available raw materials, culture, nature of the soil and type/weight of the building. As saw in chapter 2, the Neolithic pile dwelling (and not only) were built, usually, on deltas, near/in lakes, shores, rivers etc. The subsoil of these locations is usually made of deposited sediment, clay, sand and peat. Because these soils have limited carrying capacity and compressibility, the pile foundation is the best foundation type on which built a house (Murris 2011). However, piles can also be used in normal ground conditions to resist horizontal loads.
Depending on their load transmission and their functional behaviour, the piles can be divided among (Abebe and Smith 2005):

- **End bearing piles** (or point bearing piles): they transfer their load on to a firm stratum located at a considerable depth below the base of the structure and they derive most of their carrying capacity from the penetration resistance of the soil at the toe of the pile (Fig.59). Even in weak soil a pile will not fail by buckling and this effect need only be considered if part of the pile is unsupported, i.e. if it is in either air or water. Load is transmitted to the soil through friction or cohesion. However, sometimes, the soil surrounding the pile may adhere to the surface of the pile and causes "Negative Skin Friction" on the pile. This, sometimes have considerable effect on the capacity of the pile. Negative skin friction is caused by the drainage of the ground water and consolidation of the soil. The founding depth of the pile is influenced by the results of the site investigate on and soil test.

- **Friction piles and cohesion piles**: their carrying capacity is derived mainly from the adhesion or friction of the soil in contact with the shaft of the pile (Fig.59):
    - **Cohesion piles:** these piles transmit most of their load to the soil through skin friction. This process of driving such piles close to each other in groups greatly reduces the porosity and compressibility of the soil within and around the groups. Therefore, piles of this category are sometimes called compaction piles. During the process of driving the pile into the ground, the soil becomes moulded and, as a result loses some of its strength. Therefore, the pile is not able to transfer the exact amount of load which it is intended to immediately after it has been driven. Usually, the soil regains some of its strength three to five months after it has been driven.
    - **Friction piles:** these piles also transfer their load to the ground through skin friction. The process of driving such piles does not compact the soil appreciably. These types of pile foundations are commonly known as floating pile foundations.
- **Combination of friction and cohesion piles:** An extension of

the end bearing pile when the bearing stratum is not hard, such as a firm clay. The pile is driven far enough into the lower material to develop adequate frictional resistance. A farther variation of the end bearing pile is piles with enlarged bearing areas. This is achieved by forcing a bulb of concrete into the soft stratum immediately above the firm layer to give an enlarged base. A similar effect is produced with bored piles by forming a large cone or bell at the bottom with a special reaming tool. Bored piles which are provided with a bell have a high tensile strength and can be used as tension piles

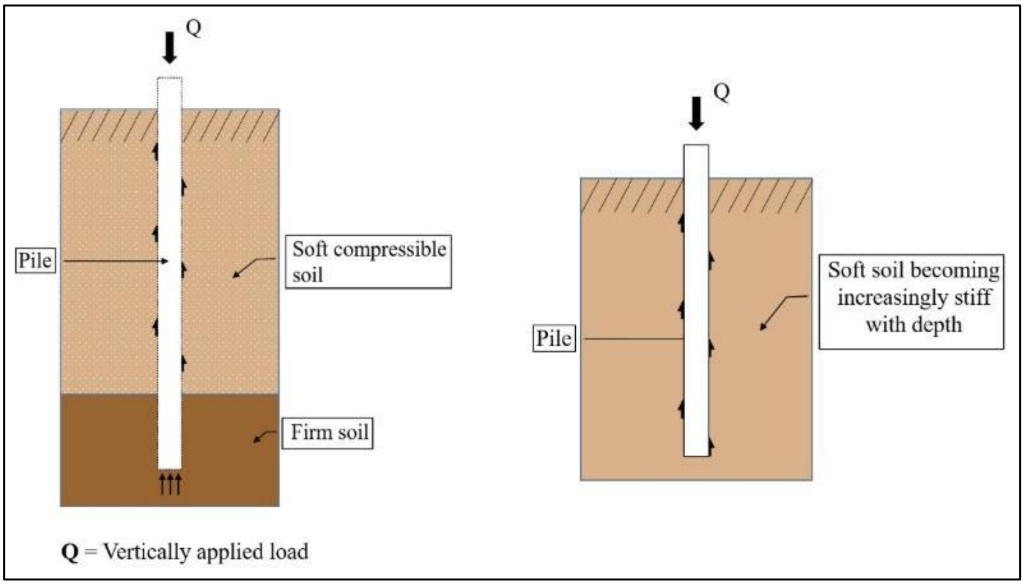


Fig.59. Left: End bearing piles. **Right**: Friction or cohesion pile (image by the author).

A pile can be driven, drilled or jacked into the ground. The type of pile influences the method selected for its installation. With respect to effects on the soil (Fig.60), pile could be classified as (Ascalew and Ian Smith 2007):

- **Driven piles** (or displacement piles).
  In the process of driving the pile into the ground, soil is moved radially as the pile shaft enters the ground. There may also be a component of movement of the soil in the vertical direction.

- **Bored piles** (or non-displacement piles).

A void is formed by boring or excavation before piles is produced. Bored piles can be produced by casting concrete in the void.

- **Screwed piles**.

  They are a type of deep foundation that can be installed quickly with minimal noise and vibration. Screw piles are wound into the ground, much like a screw is wound into wood. This is an efficient means of installation and coupled with their mechanism of dispersing load, provides effective in-ground performance in a range of soils, including earthquake zones with liquefaction potential.

Driving of piles is a repulsive technique. The soil is compacted and pressurized. This results in a better carrying capacity of the pile. Drilling and pulsing are techniques that make use of the removal of ground.

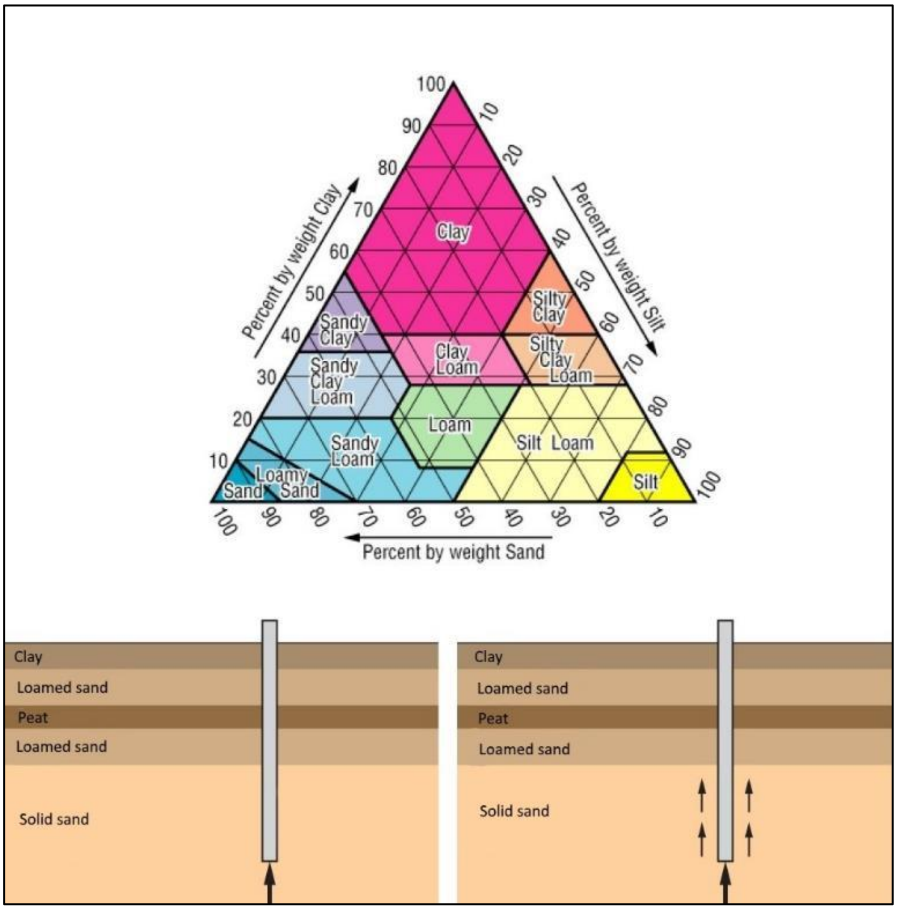


Fig.60. Upper: Different soil types subdivided by their weight of sand, clay and silt (Soilinfo 1999). **Lower, left:** point resistance in a foundation pile (Geotechnical engineering office,

Hong Kong, 2006); **right:** point resistance of a foundation pile (Geotechnical engineering office, Hong Kong, 2006).

This removal may lead to relaxation of the ground, which has negative consequences for bearing capacity. For driving piles both techniques, repulsing soil as soil removal, can be used (Rij 2005).

2.10. STRUCTURAL DESIGN: LOAD FORCES AND LOAD CAPACITIES

Normally, pile foundations consist of pile cap (e.g. a platform) and a group of piles. The pile cap distributes the applied load to the individual piles which, in turn, transfer the load to the bearing ground. The individual piles are spaced and connected to the pile cap trimmed in order to connect the pile to the structure at cut-off level, and depending on the type of structure and eccentricity of the load, they can be arranged in different patterns. The efficiency of pile group depends on the following factors:

1. Spacing of piles.
2. Total number of piles in a row and number of rows in a group.
3. Characteristics of pile (material, diameter and length).

The loads acting on the foundation piles are the vertical ones and the horizontal ones. The vertical loads, or axial loads, consists of the weight of the total construction. The main horizontal loads, or lateral loads, are wind, hydrodynamic and ice loads. These loads cause shear forces and bending moments witch have to be transferred to the soil.

2.10.1. Vertical Load Carrying Capacity

A pile foundation carries the vertical load to a bearing ground layer in the soil. This is possible due to two reaction forces in the ground: the point capacity and the shaft capacity. The bearing capacity for the vertical forces is mainly derived from the point resistance. The point resistance is the force at the tip of the pile (Sabbe and Serruys 2008). This resistance is caused by the reaction of a bearing stratum in the soil. The shaft capacity is the force that engages the shaft of the pile, caused by the adhesive force of the soil. The piles should be driven about one meter in the bearing sand layer to develop a good bearing capacity. When piles are placed too close to each other, the bearing capacity of each pile will reduce. Therefore, the piles should be at least placed 2.5 times the thickness of the pile from each other. For a wooden pile, the distance is about 0.6 meter (Rij 2005). In case of a pile subjected to tension, the adhesive force will only contribute to the towing capacity of the pile. Therefore, the total capacity to withstand the tensional forces is equal to the adhesive force on the shaft (Sabbe and Serruys 2008).

2.10.2. Horizontal Load Carrying Capacity

The horizontal load on the pile foundation is dependent from the forces of the wind and water on the structure above ground. The transfer of the horizontal forces to the ground can take place in three ways:

- By constructing some of the piles under a slope.
- By friction and passive soil pressure (only with simple constructions).
- By the inclusion of bending moments in the piles.

It is generally assumed that piles under a slope only transfer normal forces. However, this is only the case if the slope of the pile no more than 4:1 (vertical: horizontal). For larger slopes, the horizontal loads will lead to increasing moments in the pile (Rij 2005). The most important factors for the design of the piles are the stiffness of the pile and the interaction of the pile with the soil. The lateral load is initially carried by the soil, near the soil surface. Because the soil is compressed elastically, a part of the pressure of the pile is transferred to deeper soil layers. Two situations are distinguished. A horizontal load at a short pile and a horizontal load at a relatively long pile (Sabbe and Serruys 2008) (Fig.61).

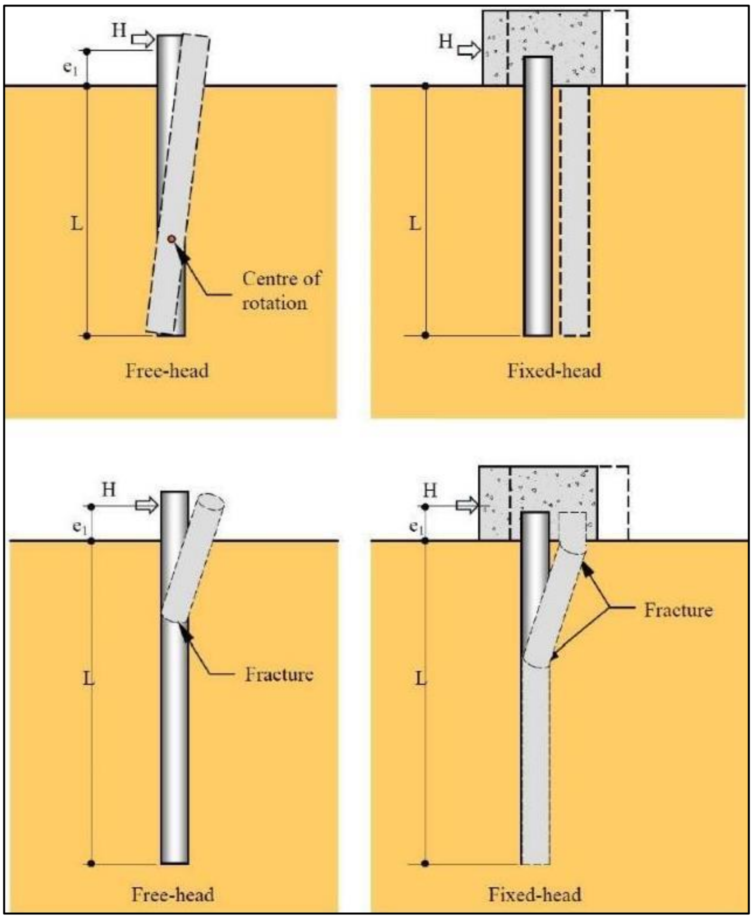


Fig.61. Upper: the effects of horizontal load on a short pile. The left picture shows the results in case of a free head. The right picture shows the results in case of a fixed head (Sabbe and Serruys 2008). **Lower:** the effects of horizontal load on a long pile. The left picture shows the results in case of a free head. The right picture shows the results in case of a fixed head (Sabbe and Serruys 2008).

2.10.3. Horizontal Load at Short Piles

A short rigid pile behaves differently from a long pile (Fig.61). A short pile is a pile with a length to width ratio less than 10/1 or 12 /1. Such type of piles will start to rotate in case they are lateral loaded. Underneath the point of rotation, passive soil pressure arises. Since the pile may not fail, the passive soil pressure may not exceed the passive resistance. Otherwise, the pile will rotate (Sabbe and Serruys 2008). To calculate the ultimate lateral resistance of short rigid piles, the resistance on both sides of the rotation point has to be considered.

The Brinch Hansen Method

The Brinch Hansen (henceforth BH) method is used to calculate the ultimate lateral resistance of a pile. Unlike other methods, the BH separates the soil resistance at different depths and also allows the term of cohesion in the calculation. The model is also suitable for layered systems with different types of soil. Another difference is about the pile behaviour: this method does not fix the pile at a fixed depth, but keeps this point variable. If the load and the pile width are known, the pile length and the location of the rotation point can be found by means of an iterative procedure. On the soil pressures, BH method takes into account both the active and passive earth pressures. The BH is also suitable for all types of soil and for layer systems (Ruigrok 2010).

This is usually done by using the method of Brinch Hansen; a relative simple method that can be used for both uniform and layered soils (Sabbe and Serruys 2008).

2.10.4. Horizontal Load at Long Piles

A long pile will, contrary to a short one, not rotates duo to its length. The passive resistance of the lower part of the pile is larger. Instead the risk of rupture occurs (Fig.61). Therefore, the pile must be dimensioned strong enough to withstand this type of failure *(*Sabbe and Serruys 2008). To gain insight into the passive resistance of a long pile, the theoretical situation can be examined where an infinitely long pile is used. In that case, the passive resistance of the soil against the collapse of the pile is infinite.

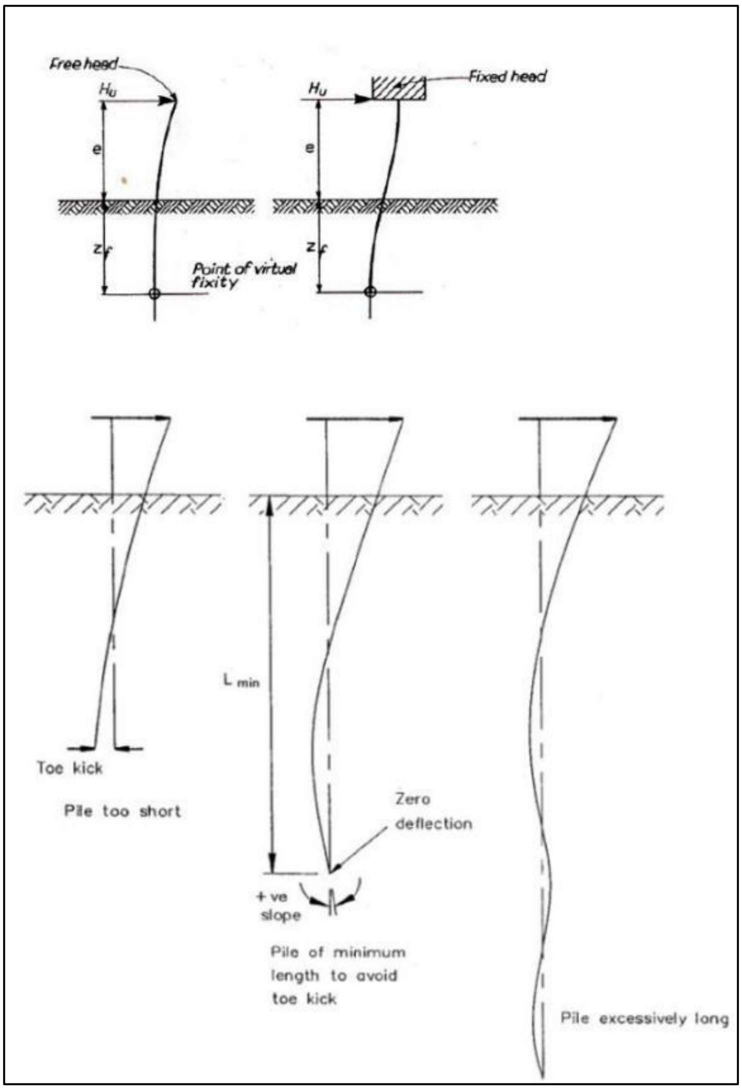


Fig.62. Upper: determining the maximum load on the piles is only by the extreme moment of resistance of the pile shaft (Sabbe and Serruys 2008). **Lower:** the minimum length is equal to the length where no diversion at the bottom of the pile occurs anymore. This is also the length that, when granting the pile, no additional diversion will occur on the surface of the soil (Sabbe and Serruys 2008).

The maximum load on the pile is thus determined only by the highest moment of resistance of the pile shaft (Fig.62). The maximum moment is then determined by the force times the arm on which it operates. As already indicated, the allowable displacements are limited. It is therefore necessary to check if the maximum deflection is not exceeded (Sabbe and Serruys 2008).

2.10.5. Pile Length Below Ground *vs* Above Ground

In order to build a solid construction a minimum length of the pile in the soil is required. This minimum length is equal to the length where no diversion at the bottom of the pile occurs anymore. This is also the length that, when granting the pile, no additional diversion will occur on the surface of the soil (Sabbe and Serruys 2008).

2.10.6. Load Sharing Effect

Because of the natural distribution of the material properties of wood, piles can sometimes be dimensioned with a higher strength. This is called the load sharing effect. Piles with a lower strength may deform. Therefore, the load on the pile can be redistributed to adjacent piles with a higher strength. However in order to dimension on the load sharing effect, the piles must be under a rigid foundation element. Otherwise, the redistribution cannot occur (Kuilen 2005).

2.11. WOOD DEGRADATION

The conservation of the wood is strictly connected with the condition of the soil where the artefact is lying. Usually, as many pile dwelling sites show, submerged wood could be conserved for a very long time. On the other hand, the parts not submerged will easily rot as result of wood rot generating fungi (Filley *et al.* 2001; Fraaij 2007; Srivastava *et al.* 2013).

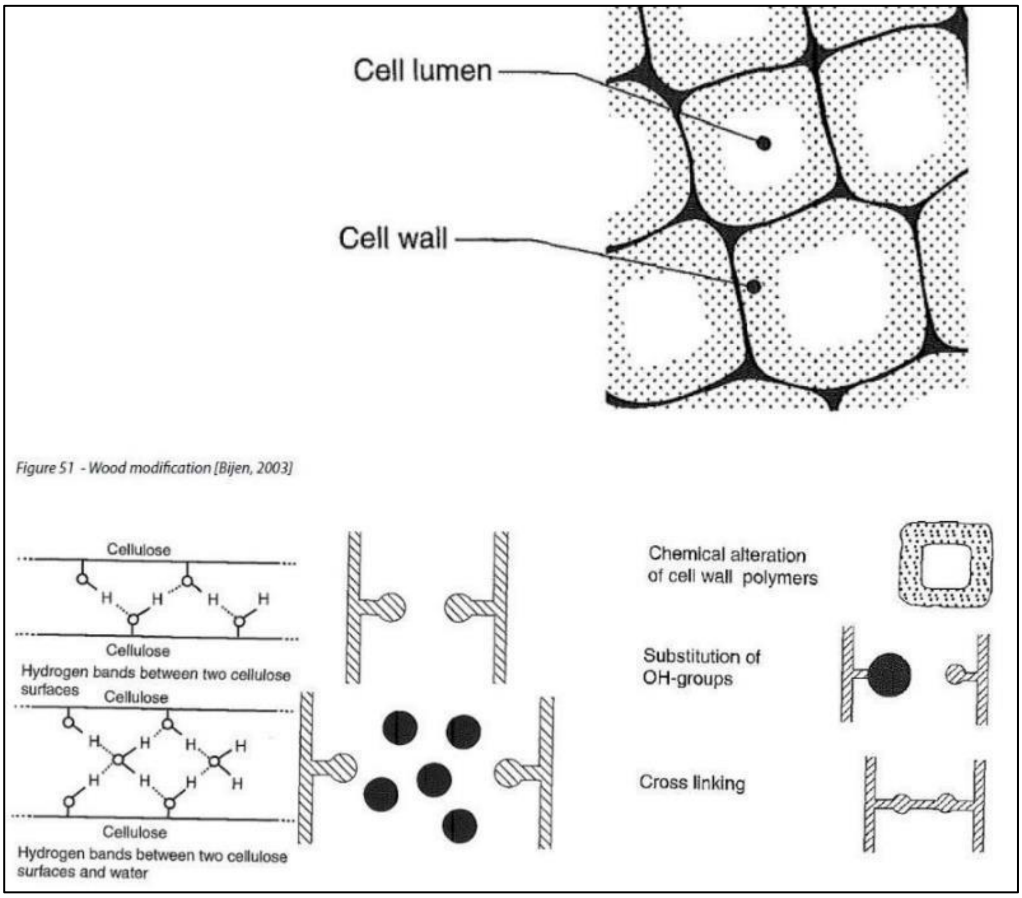


Fig.63: Wood's cellular structure (Bijen 2003).

2.11.1. Wood Rot Generating Fungi

These type of fungi (e.g. *Pleurotus ostreatus*, *Trametes versicolor* etc.) produce enzymes, achieving the degradation of cellulose and lignin (Fig.63). The strength of the wood will decline in a short time. These fungi form hyphae, which penetrate the wood and proliferate and the wood will eventually fall apart. The hyphae form a network, the mycelium on the surface of the wood. This mycelium transported nutrients and water.

This results in a higher moisture content in the wood and eventually rot will occur (Filley *et al.* 2001; Bijen 2003; Fraaij 2007; Srivastava *et al.* 2013) (Fig.64,65). Generally, wood will rot if the moisture content is at least 21 weight percent and if the temperatures is between 5 and 40 degrees Celsius.

Fig.64. Upper: in order to rot, wood needs oxygen and water. Therefore, the rot will occur on the surface of the water (Fraaij 2007). **Lower:** wood rot (Fraaij 2007).

In addition, the presence of oxygen is necessary and the fungi must have a breeding ground in order to survive. As long as the pile foundation is not above the water, there is insufficient oxygen for this process to start. This will allow no rot, as long as this condition is no fulfilled (Bijen 2003).

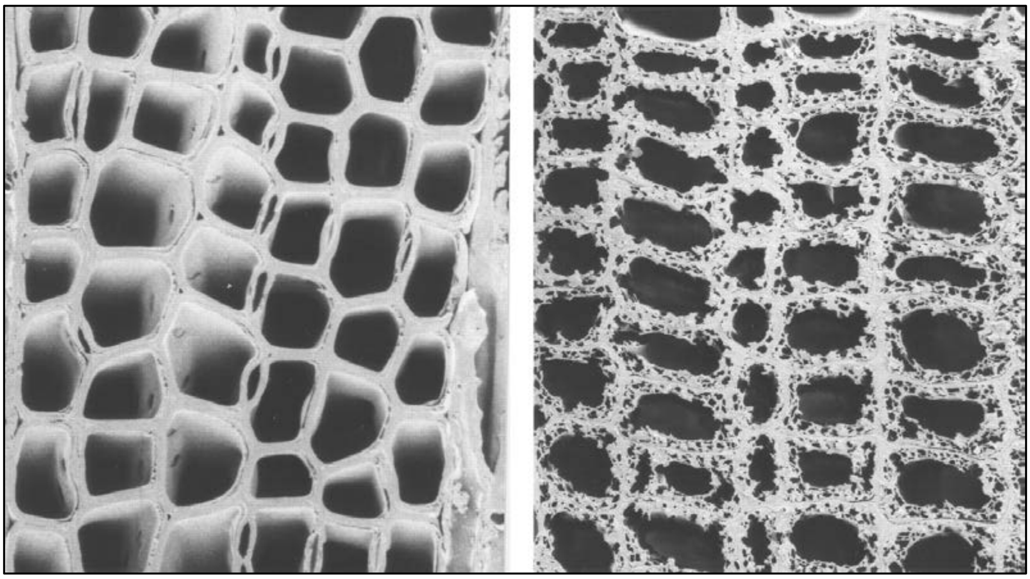


Fig.65: Scanning electron micrographs of transverse sections from sound wood of Cedar (*C. libani*) (left) and decayed wood from the king's cedar coffin showing advanced stages of soft rot (right). Cavities formed within the S2 layer of the secondary cell wall are diagnostic of soft-rot attack. Tracheids shown in the micrographs are ≈50 μm in width (Filley *et al.* 2001).

2.11.2. Degradation Phenomena of Wooden Piles Above Ground

The influence of the environment on the structure is above ground different from below the ground. However, the phenomenon wood rot can occur also above ground. In the presence of water, wood rot can occur on the edge of the water with the air. Details about this degradation mechanism can be found in chapter two. Besides wood rot, also degradation may occur due to animal attack (Bijen 2003).

2.11.3. Animal Attack

Wood can be affected by various species, like insects (especially *larvae*), marine borers and crustaceans (Fig.66). With respect to the wood damage, the most important are the marine borers, shipworms and gribble. The shipworms are the most destructive. Immature shipworms enter the wood trough small openings. They use the wood for shelter and food and excavate tunnels inside the wood. This can cause structural problems. Because of the little exterior damage, it is hard to see if the wood is damaged by shipworms.

The gribble excavates tunnels in the outer part of the wood. Therefore, the outer part will erode away. Insects will mostly attack the sapwood, which occasionally cause structural damage. Infected wood will show fine bore dust as a result of the presence of insects (Bijen 2003).

ATTACK BY	SORT	CONDITIONS TO ATC	SPECIES	RECOGNISABLE	RISK
Fungi		Not submerged Wood Oxygen water content >22% Appropriate temperatures (19-31 degree Celsius)	Brown rot (or cubic rot)	Brown colour Cubic structure of degraded wood	Structural threat Decomposes the cellulose and hemi-cellulose
			White fungi	Wood gets white colour and is pulverized, mostly related to hardwoods	Structural threat Destroyed lignin
			Soft rot	Linked with wood exposed to soil or water	Structural threat Decomposes the cellulose and hemi-cellulose.
			Wood-disfiguring fungi	Blue strain	No structure threat, affect of appearance
Insects	Beetles	Dry conditions	Death watch beetle	Attack of sapwood	Structural threat
			Common Furniture beetle	Attack of sapwood	Structural threat
			House Longhorn beetle	Attack of softwood	Structural threat
			Powder post beetle	Attack of sapwood of hard woods Fine bore dust bellow surface	Structural threat
	Termites		Divers species	Hardly any signs: by pounding hollow infested area's can be detected	Structural threat
	Marine borers	Salt of brackish water	Shipworms	Hardly any signs on outside. Inside it excavates tunnels.	Structural threat
			Gribble	Surface wood becomes sponge-like, particularly at water line	Structural threat
Bacteria		All environments, oxygen is not necessary.	Divers species	Wood rot	On short term damage duo to their slow enzyme production. After many years it can become structural threat
Weathering	UV			Grey colour change	No structure threat, affect of appearance
	Moisture				If moisture content >20% it can cause threat by insects etc. (see above)
Chemicals	Strong acid or strong alkaline				Deterioration of wood

Fig. 66: Different kinds of wood degradation (Fraaij 2007).

2.12. STILT STRUCTURE ABOVE GROUND

There are different methods to construct a stilt construction underneath a stilt house (Fig.67). One possibility is to extent the foundation piles to the dwelling (C, D). Another possibility is to use another type of construction on top of the foundation (A, B). In this way, different materials can be used for the pile construction under and above the ground. This might be useful because the environment is different and other loads will influence the construction. Therefore, in this chapter is looked at the pile construction above ground. The forces on the construction are described. Besides the most important durability, aspects of the three main building materials are discussed.

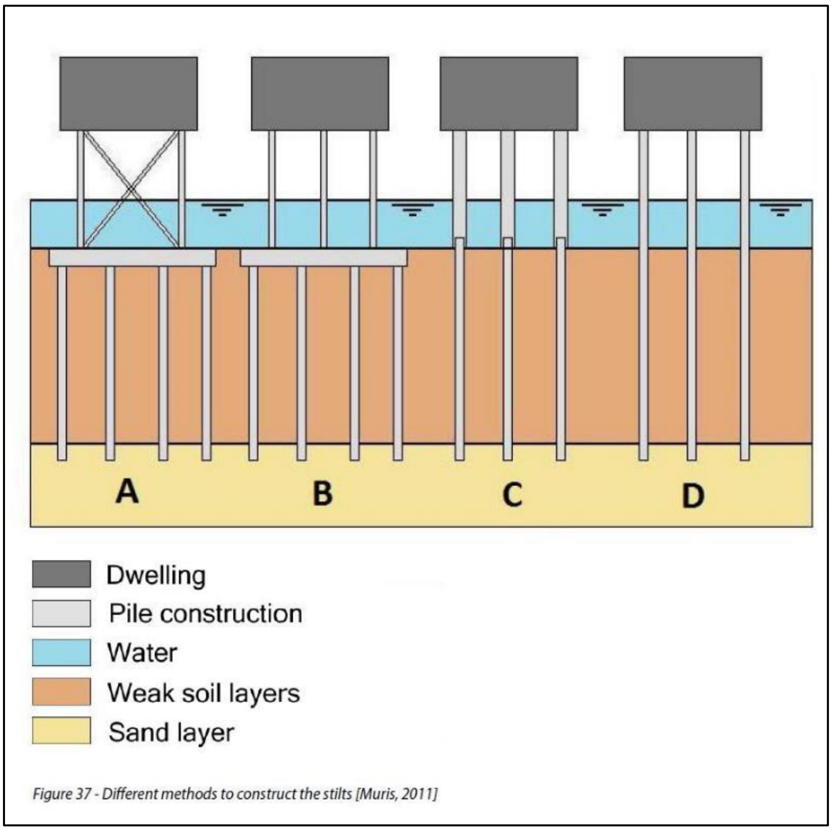


Fig.67: Different methods to construct the stilts (Muris 2011).

2.12.1. Horizontal Force of the Water

This paragraph describes the effects of the water on the construction, because when building a stilt house the exceptional situation arises that a significant water flow can be part of the total horizontal load. When stilt houses (partly) stand in the water, the force of the water on the structure has to be taken into account.

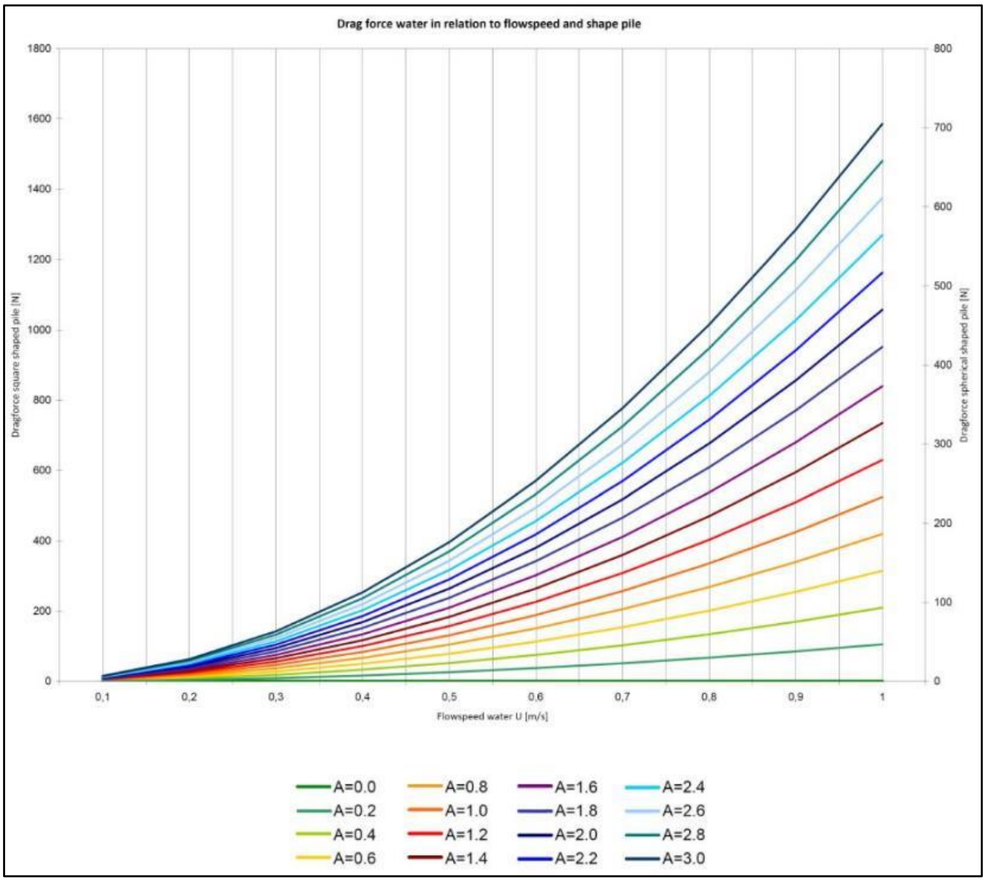


Fig.68: Relation between flood speed and drag force in a case of a square shaped or spherical shaped pile (Muris 2011).

This force is dependent of many variables. Surface waves and turbulence in the water are two of these variables. To determine the exact load is complex. However, a quite accurate estimation of the real load can be made by calculating the drag force. The drag force is the force of the liquid on the object in the direction of relative velocity. This drag force appears to depend on the ratio of the mass density and dynamic viscosity of the liquid and the speed (in perspective to the water) and size of the object in the water (Fig.68,69,70). This ratio is shown with the Reynolds number (Battjes 2002).

$$\mathrm{Re} = \frac{\rho \cdot U \cdot l}{\eta}$$

With:

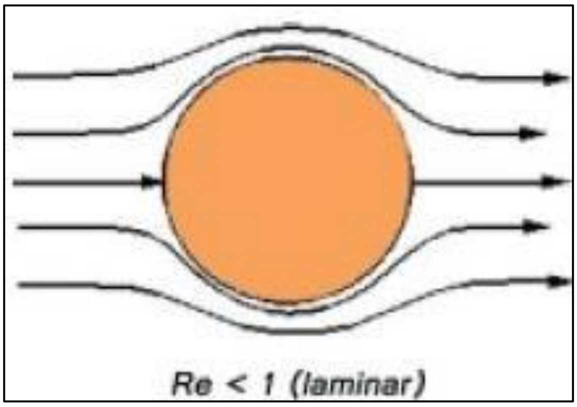
ρ = density

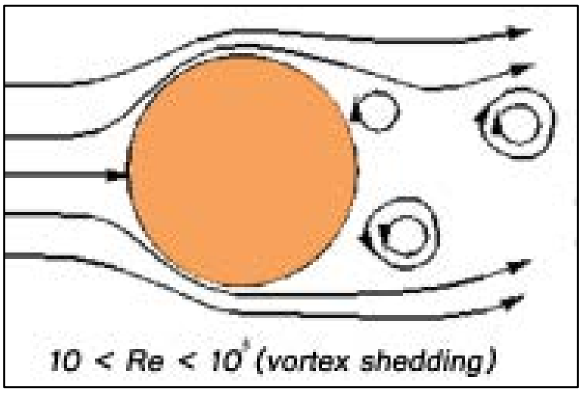
η = dynamic viscosity

U = speed of object

L = size

If the Reynolds number is much smaller than one (Re <<1) it is called laminar flow. This means it is a relatively slow flow of a viscous fluid around a small object. When the number of Reynolds is much higher than one (Re>> 1), turbulent flow occurs. This means there are many vortexes (Battjes 2002).





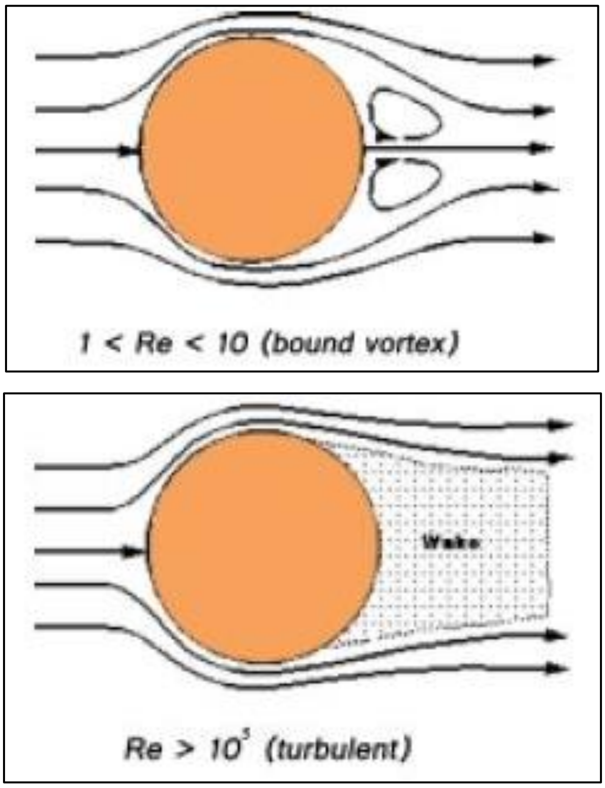


Fig.69: Differences in the Reynolds number relates to different flow patterns (Battjes 2002).

Dependent of the location of the stilt house the water might flow with different speed. This effect and the effect of the shape of the piles have their influence on the scale of the load (Battjes 2002). In the case of a weak viscous flow (Re>> 1) the drag force can be calculated with the following formula:

$$F_w = c_w \cdot \tfrac{1}{2} \rho U^2 \cdot A$$

With:

F_w = drag force (N)

C_w = drag coefficient (-)

ρ = density of liquid (kg/m^3)

U = flow speed liquid (m/s)

A = front surface object (m^2)

In the case of a highly viscous flow (Re <<1), this formula is often used as a proxy. Even though this formula is not designed for such situations. In that case, the drag coefficient is similar to the inverse of the Reynolds number (Battjes 2002). Because the flow speed in a water storage area is relatively low, the influence of the flow is generally not decisive. However, when a stilt house is being built in an area where the water level fluctuates, this flow should indeed be taken into account. Apart from the horizontal force of the water on the columns, it is also important to realize that in reality the vertical distribution of the velocity is not uniform. The distribution is influenced by the bed shear stress. This results in logarithmic distribution of the shear stress.

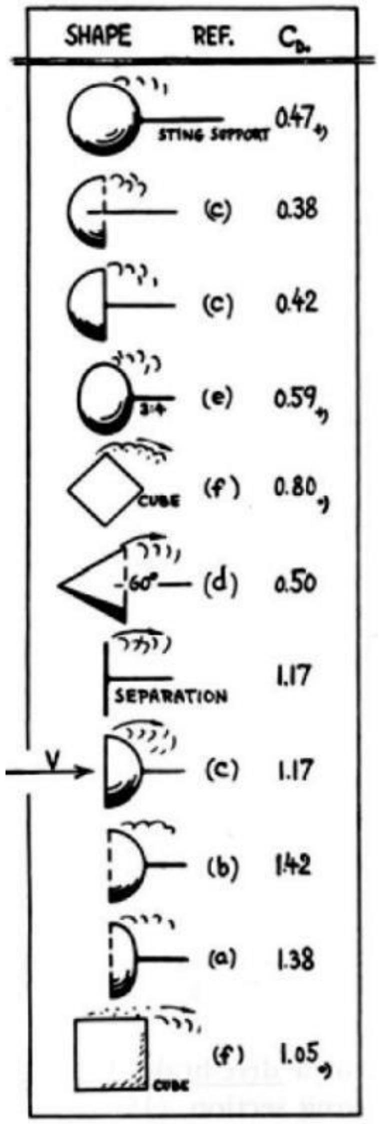


Fig.70: The drag coefficients of basic shapes (Usna 2006).

Because of this difference in speed, the horizontal pressure on the piles is on the surface higher than at the bottom. This creates a resultant vertical pressure gradient which results in a vertical acceleration of the water to the bottom. This downward flow curves at the bottom into a spiral downstream movement (also-called a horseshoe vortex). As a result of this movement, erosion can occur around the pile base. If necessary, measures should be taken to prevent this from happening (Battjes 2002).

2.12.2. Cyclical Effects

The forces on the structure above ground can have much impact on the foundation. If the horizontal forces from for example the water flow occur in a cyclical nature, the bearing capacity of pile foundations can be greatly reduced.

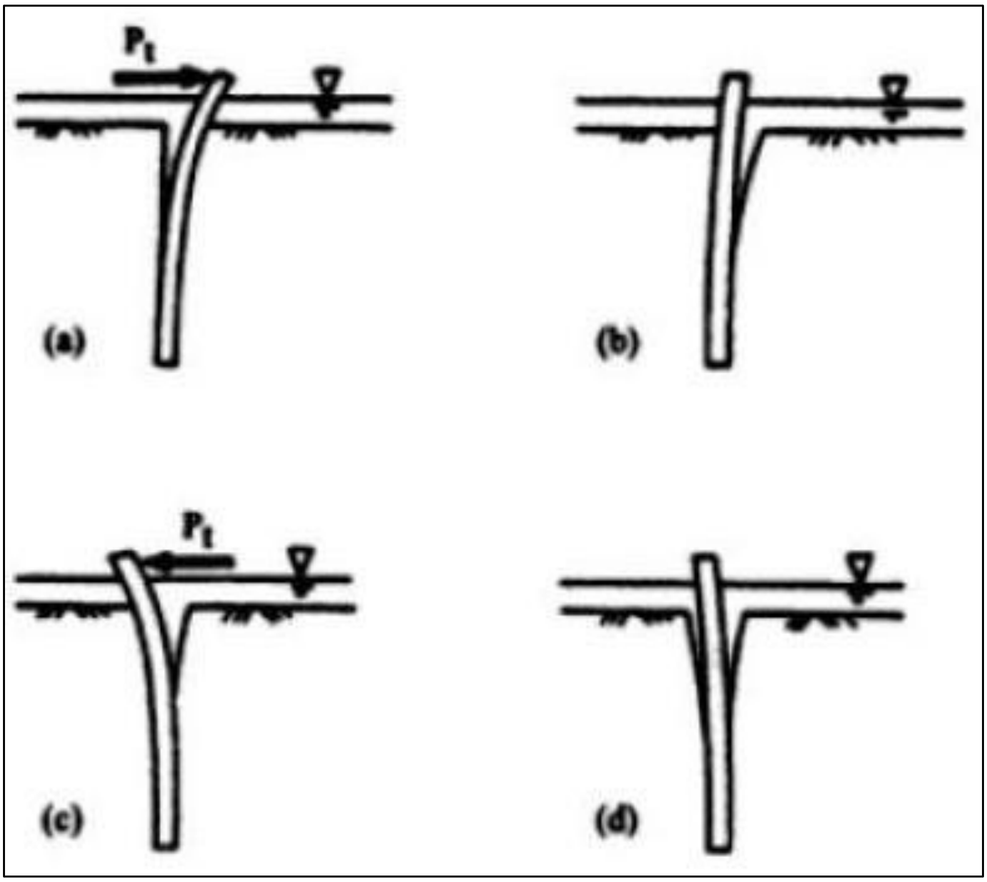


Fig.71: Cyclical effects (Sabbe and Serruys 2008).

Besides the horizontal load of the water, also wind or waves can cause a cyclical load on the construction (Fig.71). These cyclic loadings will reduce the shaft bearing capacity of a pile. The extent, to which the bearing capacity decreases, is influenced by the number of cycles. Especially in clay soils, plastically deforming easily occurs. Some cyclic loads may even lead to a reduction by a factor of 1/3 to 2/3 compared to the mean bearing capacity. The effects of this process increases as the length of the pile structure in the soil is shorter (Sabbe *et a.l* 2008).

2.12.3. Measures Against Horizontal Buckling

The lack of sufficient lateral support due to the reduced stiffness of the liquefied soil and the lateral deflection imposed on the pile may result in buckling (Mokhtar *et al.* 2014) (Fig.72).

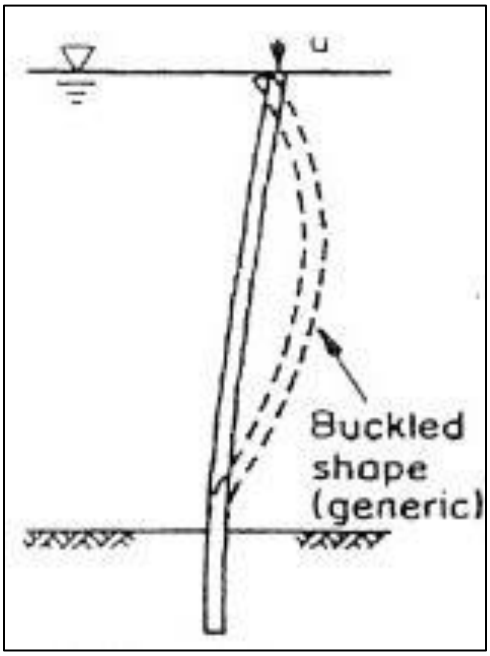


Fig.72: Buckling effect (Meyersohn 1994).

To restrict the horizontal buckling of the total construction the horizontal stiff ness of the pile structure need to be increased. This can be achieved by applying a structural bracing between the facade columns of one or more framings (Fig.73). Another option is to use piles witch have larger dimensions. However, this is architecturally not desirable. Therefore, it should be attempted to achieve the stabilization below the surface or in the superstructure.

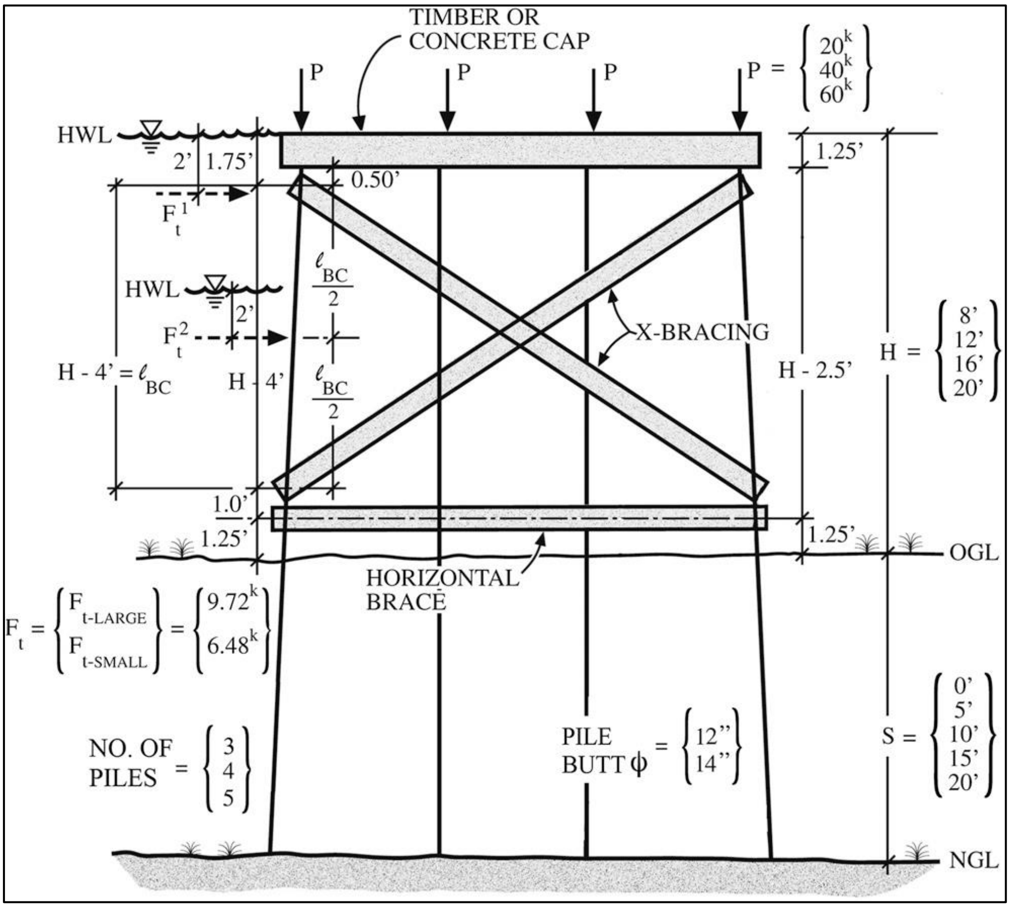


Fig.73: Typical timber pile bent–supported bridge over stream (1 ft = 0:305 m; 1 in: = 2:54 cm; 1 kip = 1,000 lbf = 4:45 kN; HWL = high waterline) (Schambeau *et al.* 2014).

2.13. SUPERSTRUCTURE

In this section the superstructure or the actual dwelling, is discussed. Because the dwelling itself can be designed in many ways, the level of detail is limited. The effect of the structure of the dwelling on the deformation of the total structure is described.

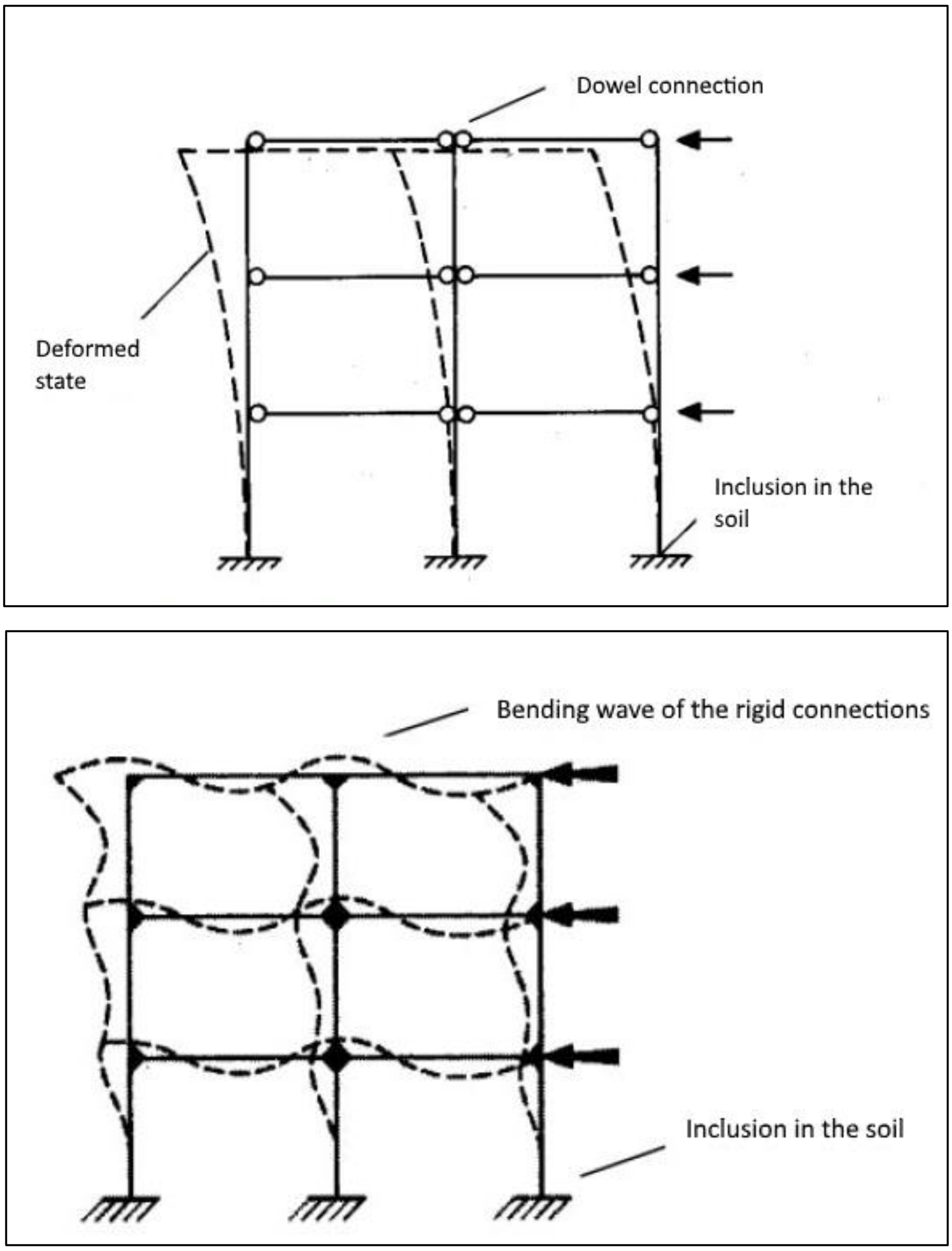


Fig.74. Upper: not fixed connection. **Lower**: fixed connections (Murris 2011).

The main forces acting on the house itself consist of wind and snow loads. These loads are not substantially different the loads that effect regular houses. Therefore, this chapter is not specifically addressed to this topic. The structural design of the house itself can also contribute to limiting the horizontal movement of the entire construction (Fig.75).

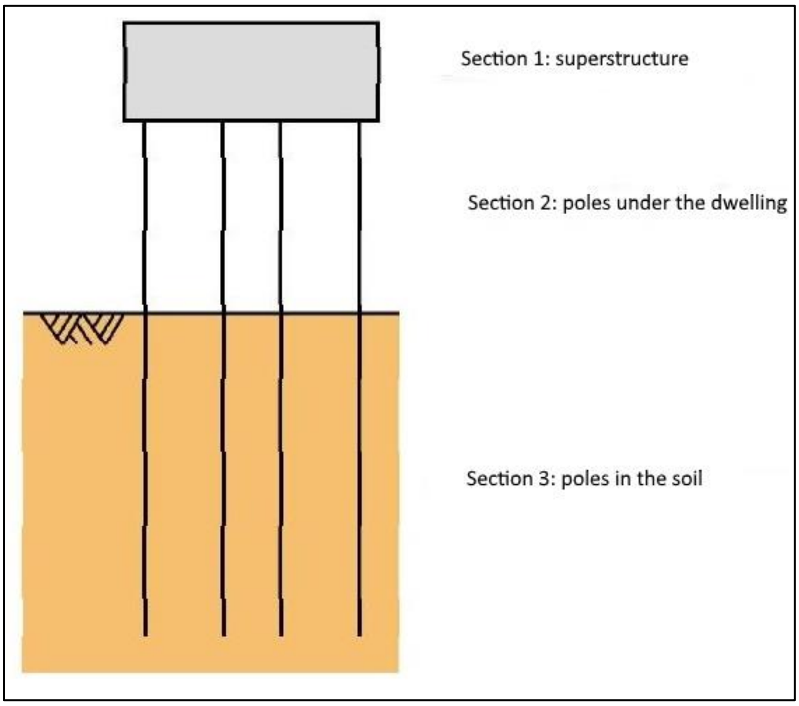


Fig.75: Section of stilt house (Murris 2011).

This can be done by using moment fixed connections between the beams of the house and the piles underneath the house. These links do not have to be used in each beam-column connection (Fig.74). By careful design, it is often sufficient to apply these fixed connections only locally. Although this can provide stability for the entire skeleton structure, this system is rarely used alone. Mostly it is combined with clamped or braced column constructions.

2.14. WOOD DEGRADATION

The main degradation mechanism that effects the appearance of the wood are *fungi*. The degradation of wood duo to blue mould fungi results in a blue-grey discoloration of the wood. These *fungi* do not affect the mechanical properties immediately, thereby the wood remains suitable for many purposes (if the moisture content is below 20%). However, the *fungi* may spread under a coating and affect the adhesion of the paint. Surface Fungi grow on walls and painted surfaces. Often they are orange, green or black and sometimes they produce toxic elements, named mycotoxins. These *fungi* are not effecting the structural properties of the wood, however the presence of these fungi is an indication of an increased moisture content.

3
HOUSE ARCHITECTURE AT LA DRAGA

“Houses mean a creation, something new, a shelter freed from the idea of a cave. „

STEPHEN GARDINER

3.1. ARCHAEOLOGICAL EVIDENCES AND HOUSE ARCHITECTURE

The reconstruction process of the house was twofold. From one side there were all those scientific process needed to rebuilt the ancient architectonic forms that is, starting from the archaeological finds, we reconstruct the house architecture studying both other similar archaeological cases and modern examples provided by the ethno-archaeology and by theoretic models built starting from these modern models. On the other side, we aimed to go beyond the result of the reconstructive process, trying to make transparent the full process of model creation (Demetrescu 2015) on the basis of the modern theories of the Cyber Archaeology that consider the authenticity of the reconstruction a “false dilemma” since the reconstruction is always an approximation of the past (Forte 2014b) while the core problem should be make clear and validate the reconstructive process.

3.1.1. The site

The Neolithic settlement of La Draga was discovered in 1990 halfway along on the eastern shore of Lake of Banyoles (Catalonia, Spain) during the works carried out to turn the area into a park (Fig.76). What make this site unique is that it is the only pile dwelling settlement found, so far, in the entire Iberian Peninsula. Moreover, the majority of the site was submerged in water and thanks to this condition a large quantity of perishable materials have been preserved, amongst which wooden elements were found.

The survey shown that the settlement covered an area on 8000 m^2. The stratigraphy dates the site from the end of the 6^{th} millennium BC (Bosch *et al.* 2000, 2006, 2011, Palomo *et al*. 2014). In topographical terms, the area where the village was built was a peninsula and the ground sloped steadily from east to west and from north to south. A stream flowed out of the Lake to the south of it, marshland lay to the east, and the waters of the Lake stretched away to the north and west, giving it virtually the appearance of an island. As a dwelling place, this location had numerous advantages, because it was easy to defend. In its heyday, the original village stretched for over 100 m along the Neolithic shoreline, in a north-south direction, and approximately 80 m inland towards the east. One part, comprising the Neolithic shoreline, lies beneath the waters of the Lake, but the most extensive area of the village is still on dry land. In Neolithic times, the whole settlement was out of the water, though the huts that stood right on the edge of the Lake must have been subject to frequent flooding (Tarrús 2008; Palomo *et al*. 2014).

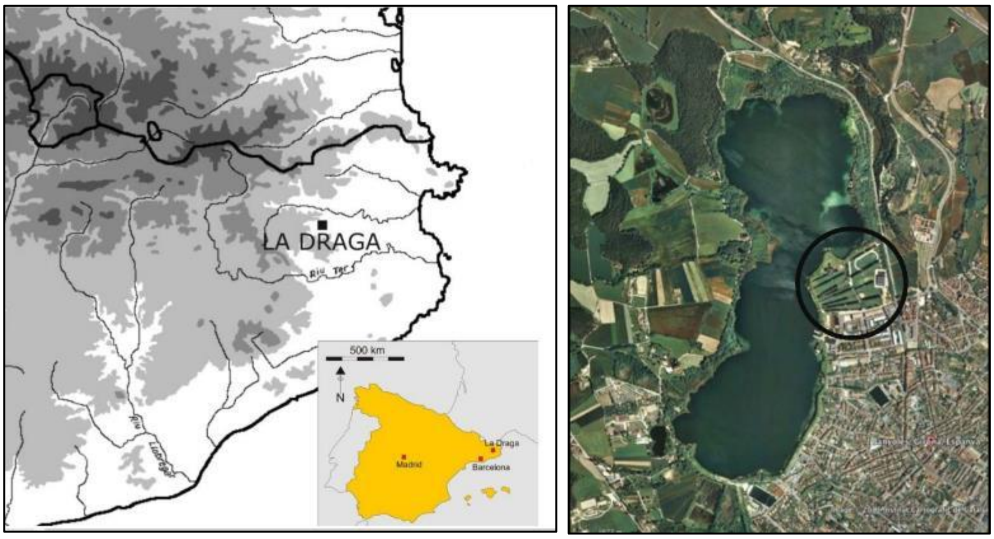


Fig.76: Localization of the site of La Draga (Palomo *et al.* 2014).

So far 4 areas has been excavated (A, B, C and D) for a total of 970 m^2 (Fig.77). The first excavations were undertaken between 1991 and 2005 under the direction of Àngel Bosch, Júlia Chinchilla and Dr. Josep Tarrús (Bosch *et al.* 2000, 2006, 2011). Between the 1991 and 1995, the excavation was focused on sector A, of about 328 m^2. In this sector, the archaeological level is above the phreatic level. Among the numerous archaeological evidences, the archaeological team found the first vegetal organic remains, that is, the points of the vertical posts, located under the archaeological level. Moreover, they found the evidences of two settlement phases. In 1994 began a collaboration with the Centre d'Arqueologia Subaquàtica de Catalunya (CASC). Thanks to this joint operation, they were able to undertake the underwater excavation of sector C, of about 310 m^2, between the 1995 and 2005.

Between 1997 and 2005 sector B was excavated (c. 132 m^2). In this sector, the archaeological level was under the phreatic layer. In this area, the archaeologists found the largest concentration of organic elements and the most relevant ones: large concentrations of cereals and fauna, bone tools, flints and large quantities of vegetal remains, wooden tools, architectonical wooden elements (Fig.78), baskets and so on. At the end of this first phase (1991-2005) 770 m^2 of the site were excavated. The results of these excavations has been published in three different monographies (Boch *et al.* 2011, 2006, 2000).

A new phase starts in 2010, coordinated by the Museu Arqueològic Comarcal de Banyoles (MACB) with the collaboration of the Universidad Autónoma de Barcelona, the Centre d'Arqueologia Subaquàtica de Catalunya (CASC), the Consejo Superior de Investigaciones Científicas - Institución Milá y Fontanals (CSIC-IMF) and the Museu d'Arqueologia de Catalunya (MAC) of Girona. In this new phase, between the 2010 and 2013, sector D was excavated. The goal was to find the continuity between sector A and sector B. The excavated area is about 55.5 m^2 (Palomo *et al.* 2014).

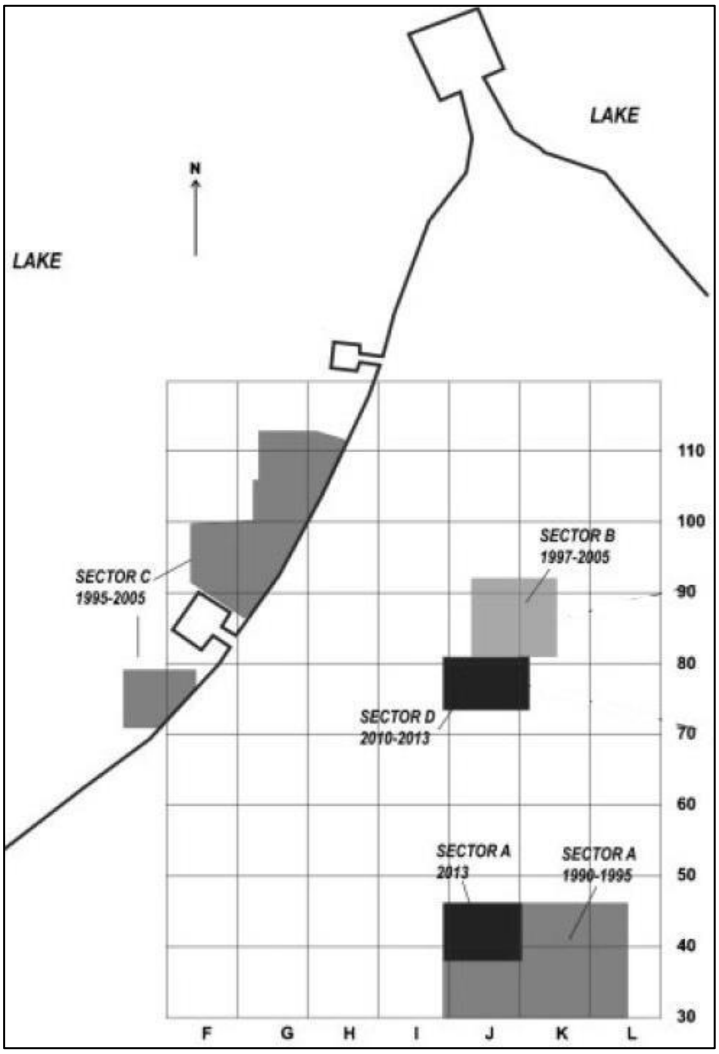


Fig.77: The site of La Draga and the sector excavated so far (Palomo *et al.* 2014).

The excavations undertaken so far, allowed identifying two main settlement phases, without any clear interruption in the stratigraphy but with two settlement patterns clearly differentiable. The first phase is characterized by the wooden structures built directly on the top of the natural layer made of lacustrine clay. The radiocarbon dating place this first phase among 5324 and 5000 cal. BC (Palomo *et al.* 2014). After the collapse of the wooden structures, a layer of travertine stones was built, probably to level the surface of the area. This second phase is placed among 5210 and 4800 cal. BC (Palomo *et al.* 2014). No organics elements related to this phase have been found. However, is possible that some of the vertical posts found still inserted into the soil could be related with this phase, but more dendrochronological studies are needed.

Fig.78: Two images of the wooden elements found at La Draga, sector D (by I. Bogdanovic).

Since the majority of the site was submerged in water a large quantity of perishable materials have been preserved amongst which many wooden tools with different functions: hunting tools (arrows and bows) (Piqué *et al.* 2015), carpentry tools like adzes and wedges (Palomo *et al.* 2013), household utensils (vessels, baskets, spoons, spatulas, beaters, combs etc.) and tools related with farm works like sickles and digging sticks (Palomo *et al.* 2011). All these objects were recovered from the archaeological level corresponding with the oldest archaeological phase.

The economic basis of this society consisted of agriculture and breeding. The study of wildlife remains shows that the breeding activity was focused on cows, sheep, goats and pigs; products of hunting had just a marginal role (Saña 2011). The analysis of carpological remains shows that agriculture was based on the cultivation of naked wheat and, to a lesser extent, on barley, legumes and berries (Antolin and Buxó 2011; Antolin 2013). These activities were possible thanks to specialized tools made of wood that have been preserved thanks the special conditions of the site.

The palynological and paleobotanical data revealed that the environment surrounding the settlement was characterised by a dense riparian forests formed by ash (*Fraxinus* sp.), willow (*Salix* sp.), elm (*Ulmus* sp.), alder (*Alnus* sp.), poplar (*Populus* sp.), elder (*Sambucus nigra*), laurel (*Laurus nobilis*) and wild grape (*Vitis vinifera* subsp. *sylvestris*). Close to surrounding slopes, oak forests were developed in profound humid soils, with dominance of deciduous *Quercus* (probably *Quercus pubescens* and *Q. robur*), and the presence of hazel (*Corylus avellana*), lime (*Tilia*), pines in the clearances (*Pinus* sp.), yew in shaded spots (*Taxus baccata*) and boxwood in the underbrush and colonising degraded areas (*Buxus sempervirens*) (Revelles *et al.* 2014, 2015, 2017; Ferme and Pique 2014). These woods provided the raw material essential for the construction. The analysis shown that majority of the wooden elements found so far in the settlement were made of oak (Lopez 2015).

3.2. ARCHITECTONICAL WOODEN ELEMENTS

All the architectonic wooden elements studied so far (López 2015) came from the sectors B, C, D. From 1991 to 2017, 1271 vertical wooden elements have been found. For the sectors B and C the equip used the information coming from the previous publications and monographies about the site (Bosch *et al*. 2012, 2011, 2006, 2000, 1999, 1998) and excavation reports (Chinchilla *et al*. 2013) while in sector D the study of the wooden elements was direct. This allowed a systematic study of them, reason why this study is focused on the finds of this specific sector. Oriol López, the archaeologist who studied the wooden rests at the Draga (López 2015), identifies four groups:

- Wooden artefacts without a specific form.
- Cut remains.
- Wooden parts with architectonic function.
- Tools.

Among these groups I focused my attention on that elements identified as having architectonic functions. The artefacts have been divided in (López 2015):

- Vertical artefacts or piles: all the wooden elements with one of the extremity, at least, stuck into the soil. 271 of these finds came from sector D.
- Horizontal artefacts: wooden elements that lying, more or less, horizontally on the archaeological layer. In sector D, 494 horizontal elements have been found.
- Tilted artefacts: all those artefacts artificially tilted and still inserted into the soil.

3.2.1. Vertical Elements

This group is formed from both forks and piles found in their original vertical position (the fallen elements has been considered as horizontal elements (López 2015). 271 vertical elements have been found in sector D. Almost the totality of the elements was made of oak (Quercus sp caducifoli). The diameter of the piles were between 11-20 mm (32 elements) and 191-200 mm (1 element) (Fig.79,80). In the 98% of the cases, the element keep the cortex, and this means that the diameter of the pile coincides with the diameter of the original piece of wood. The elements are inserted into the clayish soil at different depths and, in some cases, for more than 2 m. For what concern the high of their external part, we know that the outer part of the short forks measures about 30 cm (with variations) while, for the piles, a clarification is needed. As said before, the wood preservation is connected to its location under the water. This mean that while the underwater part of wooden elements is preserved the outer parts are lost, as the traces of wooden putrefaction testify, limiting our knowledge of the real dimension of the highest elements. The piles has been divided following its longitudinal shape: rectilinear, curved, corners and forks. Among the forms the rectilinear ones is the most diffused (155 samples) followed by the curved (89 samples), the forks (22 samples) and the corners (4 samples). In some cases it has been possible to analyse the proximal extremity of these piles, which is the part inserted into the clay. This analysis revealed six different type of ends: split direct fracture, horizontal cut, simple bevel, double bevel and conical end. Among these the double bevelled extremity is the most common (25 samples), followed by the simple bevelled extremity (96 samples).

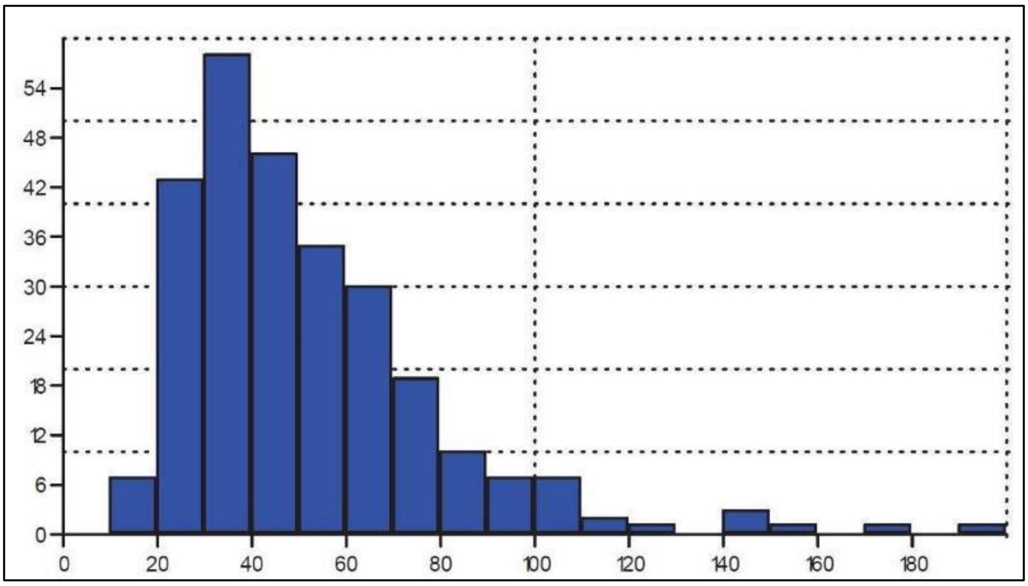


Fig.79: Graphic representation of the diameters of the vertical elements found in sector D (López 2015).

DIÀMETRE (mms)	Nº	%
01-10	0	
11-20	8	2,95
21-30	47	17,34
31-40	59	21,77
41-50	46	16,97
51-60	38	14,02
61-70	25	9,23
71-80	19	7,01
81-90	6	2,21
91-100	7	2,58
101-110	7	2,58
111-120	3	1,11
121-130	0	
131-140	0	
141-150	3	1,11
151-160	1	0,37
161-170	0	
171-180	1	0,37
181-190	0	
191-200	1	0,37
TOTAL DETERMINAT	271	

Fig.80: Diameters of the vertical elements found in sector D (López 2015).

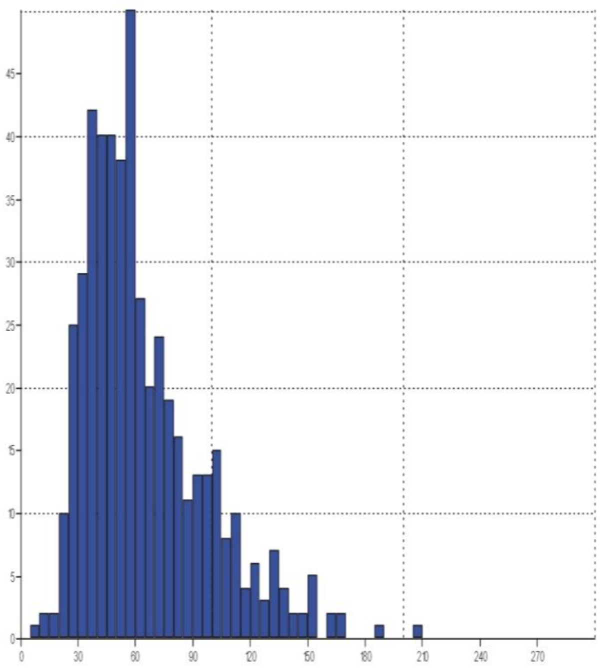
3.2.2. Horizontal Elements

Inside sector D, 494 wooden elements has been found lying horizontally. Like for the vertical piles, the majority of these (462 elements) was made of oak (*Quercus* sp caducifoli). An important aspect is that all the elements of this group belong to the same moment of utilization (Chinchilla *et al.* 2013; López 2015). The diameter of these elements (sector D) range between 7 mm and 210 mm with the majority of them between the 21-30 mm and the 111-120 mm (Fig.81). Among these, the biggest group is the one represented by the elements with a dimeter between 51-60 mm (86 elements). In some cases (485 on 494) it has been possible to measure the length of the artefacts, although in few cases corresponds to the total length due to the fragmentation and preservation of remains, the majority of which range among 40-50 cm but with elements reaching 6 m (Fig.81). Among these wooden elements, 274 had no preparation, meaning that the find preserve its entire perimeter, while 117 show two splits, and the rest between 1 and 4 splits. This difference, probably, reflect a different architectonic function (López 2015). The horizontal elements have been also divided depending on their longitudinal shape identifying five categories:

- Straight elements (211 elements).
- Curved elements (60).
- Planks (110).
- Angles (24).
- Forks (18).

As we can see, the biggest categories are the straight elements and the planks ones. The angled elements have length between 30 and 200 cm with the majority with a length between 70 and 110 cm. The forks have a length that range between 20 and 330 cm with the majority of which has a length between 60 and 160 cm.

Diàmetre (mm)	Nº	%
01-10	2	0,40
11-20	6	1,21
21-30	39	7,89
31-40	77	15,59
41-50	78	15,79
51-60	86	17,41
61-70	49	9,92
71-80	37	7,49
81-90	30	6,07
91-100	26	5,26
101-110	17	3,44
111-120	16	3,24
121-130	8	1,62
131-140	9	1,82
141-150	5	1,01
151-160	4	0,81
161-170	3	0,61
171-180		0,00
181-190	1	0,20
191-200		0,00
201-210	1	0,20
Total	**494**	



Llargada (cm)	Nº	%
01-20	13	2,68
21-40	96	19,79
41-60	94	19,38
61-80	83	17,11
81-100	45	9,28
101-120	40	8,25
121-140	32	6,60
141-160	27	5,57
161-180	13	2,68
181-200	11	2,27
201-220	12	2,47
221-240	5	1,03
241-260	3	0,62
261-280	4	0,82
281-300	2	0,41
301-320		0,00
321-340	2	0,41
341-360	2	0,41
361-380		0,00
381-400		0,00
401-420		0,00
421-440	1	0,21
Total formes	**485**	
No determinat	9	1,82
Total	**494**	

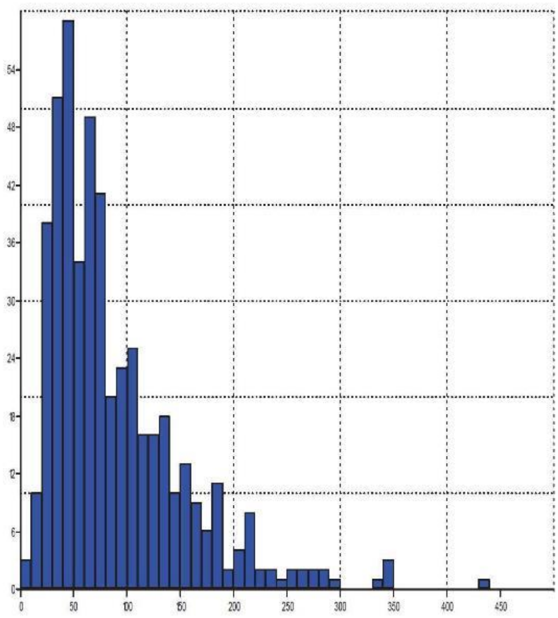


Fig.81.Top: Diameter of the horizontal elements from sector D and their graphic representation (by groups of 5 mm). **Bottom**: Length of the horizontal elements from sector D and their graphic representation (by groups of 10 cm) (López 2015).

3.2.3. Tilted Elements

This group includes a 150 piles artificially tilted (Fig.82). The archaeological team of La Draga postulated that these elements were in connection with the vertical piles and the short forks. This, and their slope degree, seems to indicate that they might be part of the overhead structure, as described in chapter 4.2. The tilted piles have diameters that range between the 14 and the 191 mm. The majority of them has a diameter between 21 and 70 mm with a peak around the 31 – 40 mm (34 elements) (Fig.83). The study of the orientation of these posts revealed that the majority of them is tilted towards West (32 elements; Fig.84) (López 2015).

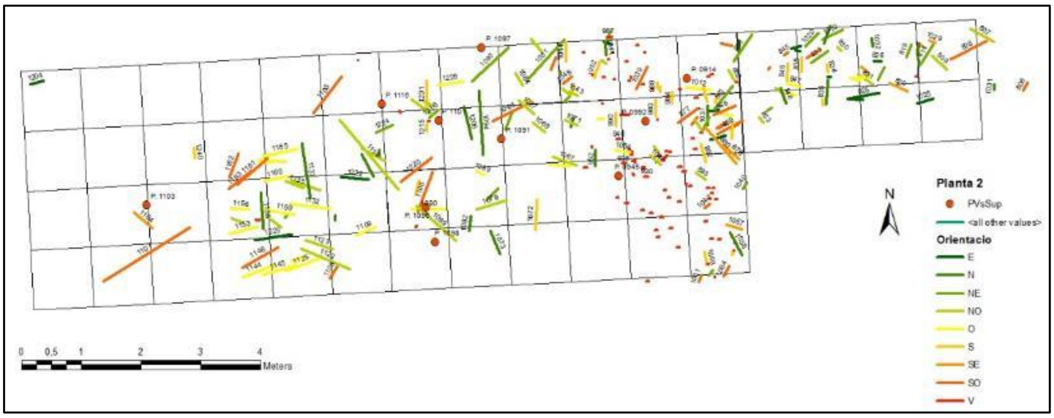


Fig.82: The tilted posts on sector D and their slope direction (I. Bogdanovic).

Diameter (mm)	Nº
14-20	2
21-30	21
31-40	34
41-50	25
51-60	25
61-70	15
71-80	11
81-90	2
91-100	5
101-110	6

111-120	1
143	1
191	1
n/d	1

Fig.83: Diameters of the tilted elements found in sector D (table by the author).

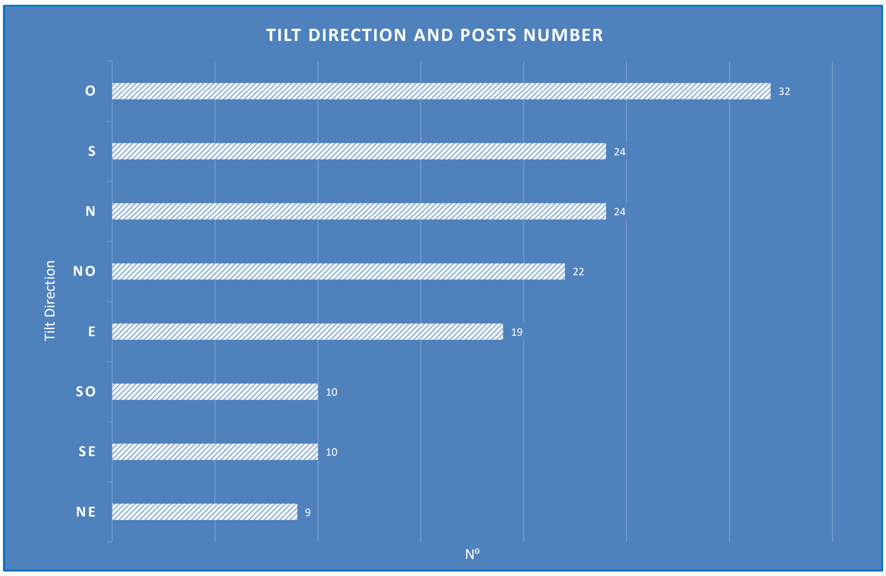


Fig.84: The posts and their tilt direction (table by the author).

3.2.4. Raw material

Almost all the 271 vertical elements found in sector D were made of oak (*Quercus* sp. Caducifoli: 252 elements). The rest of the piles were made of hazel (*Corylus avellana*: 4 elements), laurel (*Laurus nobilis*: 2 elements) and dogwood (*Cornus sanguinea*: 1 element) (Fig.85). Only the remains of 12 elements were impossible to identify (López 2015).

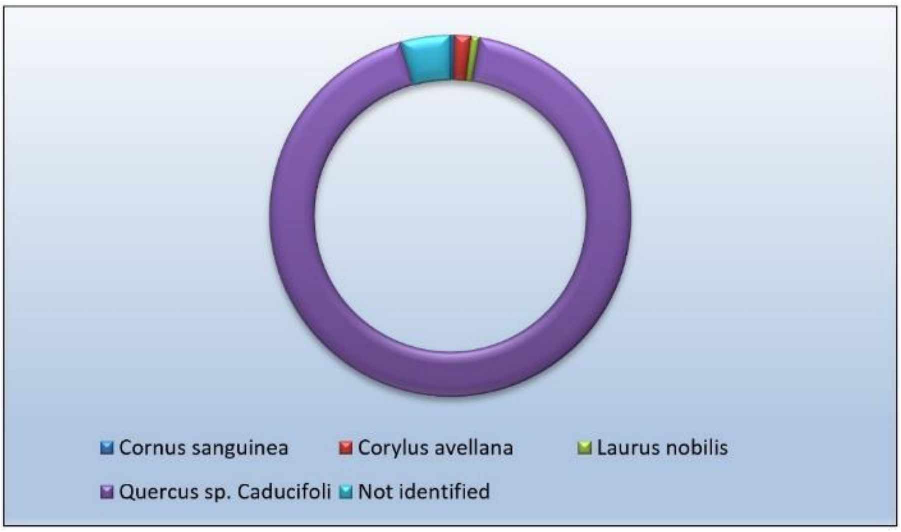


Fig.85: The different wood *taxa* of the vertical elements found at La Draga in sector D (by the author).

Of the 494 horizontal elements found in sector D, 481 were identified. As for the vertical elements the majority of the horizontal elements were made of oak (Quercus sp caducifoli; 462 elements). The remaining elements were made of hazel (*Corylus avellana*; 6 elements), laurel (*Laurus nobilis*; 6 elements) and one type of *rosacea* (Rosaceae/Maloideae; 1 element) (Fig.86). Only the remains of 15 elements were impossible to identify (López 2015).

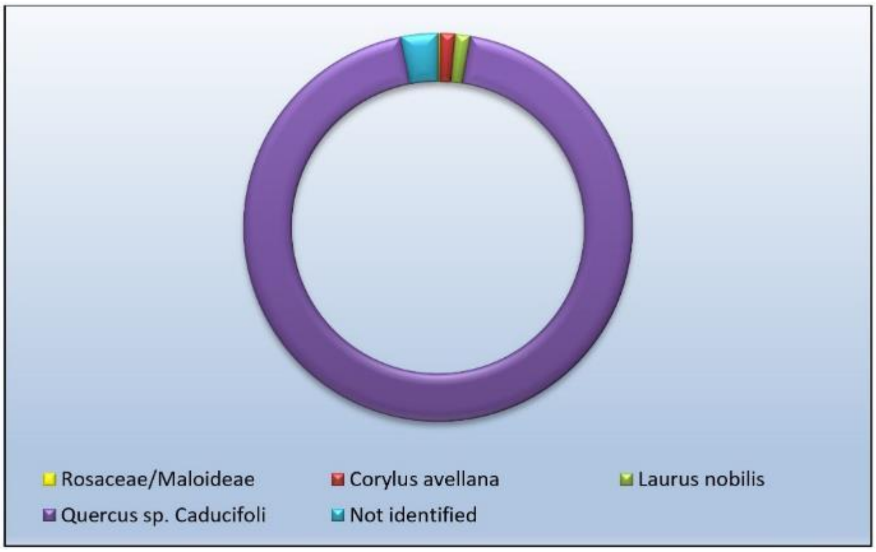


Fig.86: The different wood *taxa* of the horizontal elements found at La Draga in sector D (by the author).

3.3. EVIDENCES OF STRUCTURES/HOUSES

The analysis of the distribution of all the horizontal and vertical wooden elements is connected with the discovery of two horizontal wooden structures, or part of it, inside sector D (Fig.87). The first of the two structures it is composed by a plank, longer more than 3 m, joined to a vertical pile in form of a fork near to the soil. The other structure is composed by three horizontal elements of big dimensions, that seems to be connected forming a rectangle. In the disposition of the horizontal wooden elements connected with these two structures one can observes two different dispositional pattern: disposition North- South and irregular disposition (Fig.88,89).

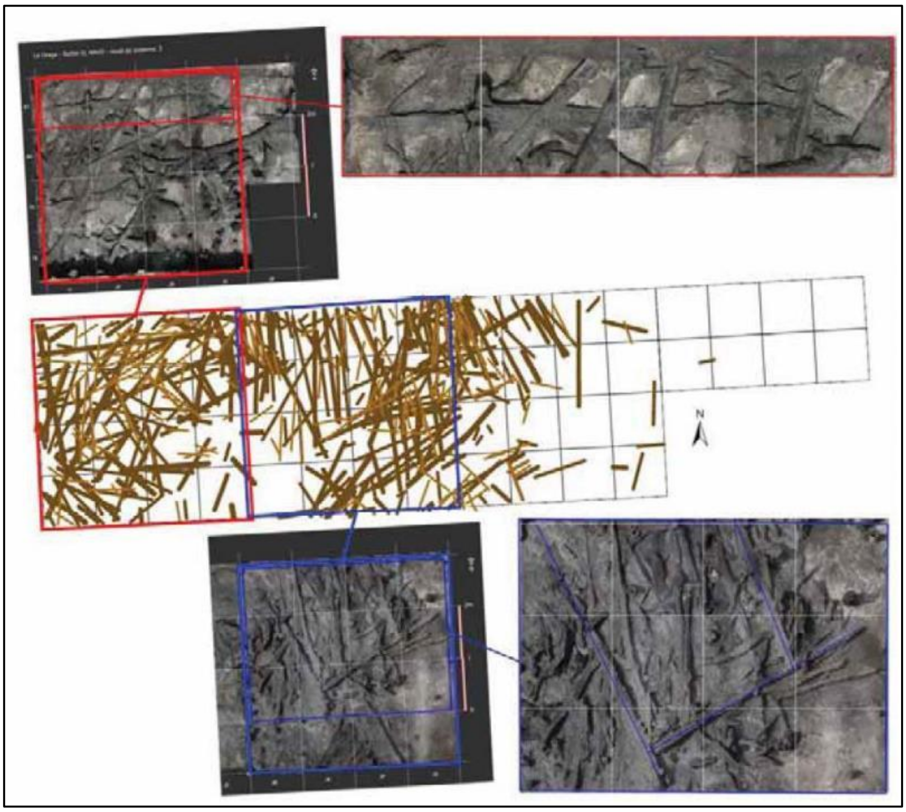


Fig.87: The two possible assemblages in sector D identified as structures (López 2015).

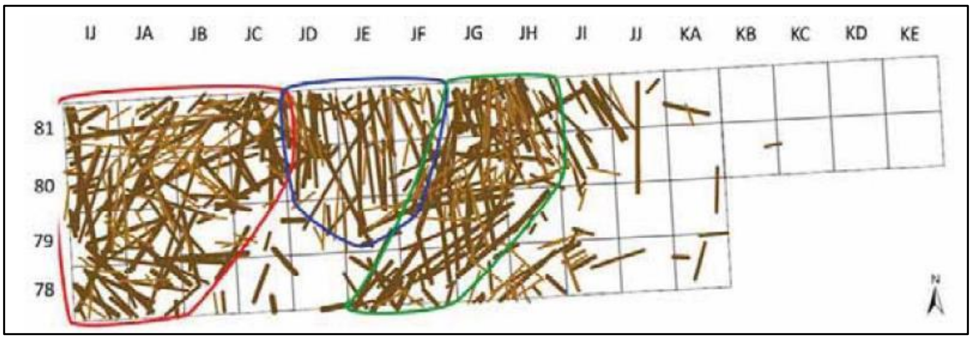


Fig.88: Localization of the horizontal elements respect the two structures (I. Bogdanovic).

The first one is situated between the quadrant IJ and JC, where we found the structure formed by the fork and the plank (Fig.88,89). The second one is connected with the three horizontal logs forming a rectangle, and involve the quadrants from JD to JF included.

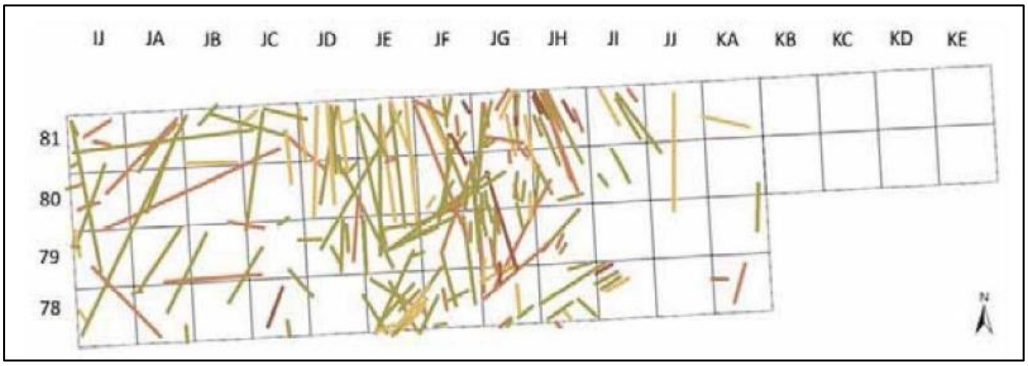


Fig.89: Distribution of the horizontal elements with traces of split in relation with the structures (I. Bogdanovic).

Among the horizontal wooden elements, the ones that need more effort to be realized are the planks. They have been obtained cutting the trunks into wedges of triangular section. They have been connected (López 2015) to the creation of the base of the structure as they disposition inside the area seems to suggest. They are oriented North-South that is perpendicularly to the structure formed by the fork and the plank described below. This suggest that these planks could be lying on the top of such structure, forming the flooring of the house. In fact, the localization of the forks on the maps shows that they cover the same area of those elements (and more). Resuming, the wooden elements found so far seems to suggest that the structures identified as houses should be composed by:

- Forks, both inserted in the soil and lying on it. The first ones had, probably, the task of hold the platform/floor of the house, while the seconds had the task of hold the ridge beam.
- Piles: both inserted in the soil and lying on it. As already said before is difficult to identify the high and the end of much of the piles. It is probable that the small ones were used with the forks to hold the floor, while the longest ones could be rests of forks or piles used for other tasks but not has wall elements since we considered that the obliquus piles composed the frame of them. It will be useful try to understand if there is any connection between the inserted forks and the smaller piles.
- Planks and trunks: they should be used both to compose the floor framework (see below) both the floor itself.

The archaeological investigation at La Draga provides the following information about structural elements.

- **Short forks:**

  A large number of piles inserted inside the natural soil. Their top end it is characterized by a natural V shape exploited to hold other piles hence the name “fork”. The lower extremity, instead, was processed in such a way as to have a pointed extremity in order to easily pierce the soil. Their average length was 1.37 m of which only 30 cm (including the V end) jutting out from the soil.

- **Long forks:**

  These piles had the same characteristics of the short forks but they were longer, fewer in number and they were found lying on the surface. The longest of them measures 3.12 m. No long fork was found *in situ* but it seems possible (measuring the other elements) that the part underground was 52 cm long, while the external part was 2.30 m long.

- **Planks:**

  This group includes planks with an artificial triangular section (obtained cutting a log in “slices” using stone tools and wooden wedges).

- **Tilted branches:**

  As for the forks, they were underground. Their external part only last for few centimetres. It is possible that they have a structural function (see below).

- **Other Horizontal elements:**

  A large number of wooden parts of different sizes and forms including trunks, planks and posts. The longest element of this group is a plank 6.27 m long.

4

RECONSTRUCTING A NEOLITHIC PILE DWELLING FROM LA DRAGA NEOLITHIC SITE

> "*How often have I said to you that when you have eliminated the impossible, whatever remains, however improbable, must be the truth?* „
>
> SHERLOCK HOLMES, THE SIGN OF FOUR

FOREWORD

Regarding our reconstruction, the first step was to create a virtual version of the architectonical wooden elements found at La Draga. Then we started to investigate all the possible architectonical arrangements fitting the archaeological data we had. The program used to undergone the reconstructive process is Rhinoceros 5. We chose this program because it is a very good mid-point between CAD programs and complex 3D modelling programs like 3D Studio Max, Maya or Blender. Moreover it has almost endless plug-ins that, basically, allow you to do whatever you want and, again, it is compatible with Grasshopper and ArchiCad, that are the other two programs we used to create the BIM process.

Once we determined the house planes and their components, we created their virtual counterpart. Since the main goal was to understand and reconstruct the house structure and not just to replicate the aesthetic aspect of each elements we created schematic solid models of them. A solid model is a complete representation of an object. It integrates mathematical data that includes surface and edge data as well as data on the volume of the object the model describes. In addition to visualization and manufacturing, solid modelling data is used in design calculation.

As said, we used Rhino 5, a very flexible and user-friendly 3D surface-modelling tool, enabling to construct NURBS (Non-uniform rational basis spline) surfaces as well as polygonal meshes for making 3D models of free-form objects. Constructing the model of an object usually concerns the making of two or more surfaces with different surface patterns. For easy handling of surface objects, you may join two or more contiguous surfaces sharing common edges to form a polysurface. Among the many ways to represent a solid in the computer, Rhino's solid is a surface or a polysurface enclosing a volume without any gaps, openings, or intersections among the individual surfaces. To obtain special form and shape effects from surfaces that are already constructed, one can use Rhino's transformation tools.

Once we had all the elements reproduced in a 3D version, we were able to work with them, trying our reconstructive theories. I would emphasize that elements not involved in this research (for various reasons), as the aesthetics aspects of the single elements or their physical and morphologic properties, when necessary may be included in the BIM process created to handle the houses of La Draga. This applies for each aspects connected to the elements we recreated: each time a new set of information about them it is discovered/produced we will implement it into the BIM model. These new information will allow us to undertake new and even more complex analysis and simulations for a better and better understanding of the Neolithic site of La Draga.

Regarding our reconstruction, the first step was to create a virtual version of the architectonical wooden elements found at La Draga. Then we started to investigate all the possible architectonical arrangements fitting the archaeological data we had. The program used to undergone the reconstructive process is Rhinoceros 5. We chose this program because it is a very good mid-point between CAD programs and complex 3D modelling programs like 3D Studio Max, Maya or Blender. Moreover it has almost endless plug-ins that, basically, allow you to do whatever you want and, again, it is compatible with Grasshopper and ArchiCad, that are the other two programs we used to create the BIM process.

Before I go any further in the description, I have to specify that all the following architectural principles, come from modern studies and, therefore, represent the ideal composition for a pile dwelling. Even if principles like physic force are the same, whether we take into account a modern house or a Neolithic one, we cannot expect to find them thoroughly followed in the ancient buildings. It seems reasonable to postulate that the ancient pile dwelling were build following experience and/or tradition rather that by knowing and following all the modern concepts that I will enlist here. However, we can and must take into account this modern information to understand the archaeological evidences, to define the different parts and to describe the ancient pile dwellings and their elements.

4.1. BASE PLANE OF LA DRAGA HOUSE

As described in chapter 2.7.3, the base plane is the complex of elements meant, whatever their form, materials and arrangement, to withstand physic forces (like gravity) in order to support the other planes of a building. Along with climate and other environmental conditions of a site, the topographical character of the ground plane influences the form of the building that rises from it. The building can merge with the ground plane, rest firmly on it, be elevated above it or depressed. The base plane is the horizontal element that sustains the force of gravity as we move around and place objects for our use on it. It may be a durable covering of the ground plane or a more artificial, elevated plane spanning the space between its supports (Pramar 1973; Ching 2014).

In a timber house, the base plane could be simple, made of the soil itself or a layer of a particular material, or complex implying a structure consisting of elements like girts, posts, joists and plates forming a structure meant to hold the material composing the floor.

The hypothesis for the base plane of the cabin of La Draga is based, firstly, on the presence of both vertical and horizontal architectural wooden elements: the so-called "short forks" (inserted into the soil), branches, beams and planks lying on the natural soil (Fig.90). In sector D, as as described in more detail in the next paragraph, some of these elements appears to be connected (Fig.90).

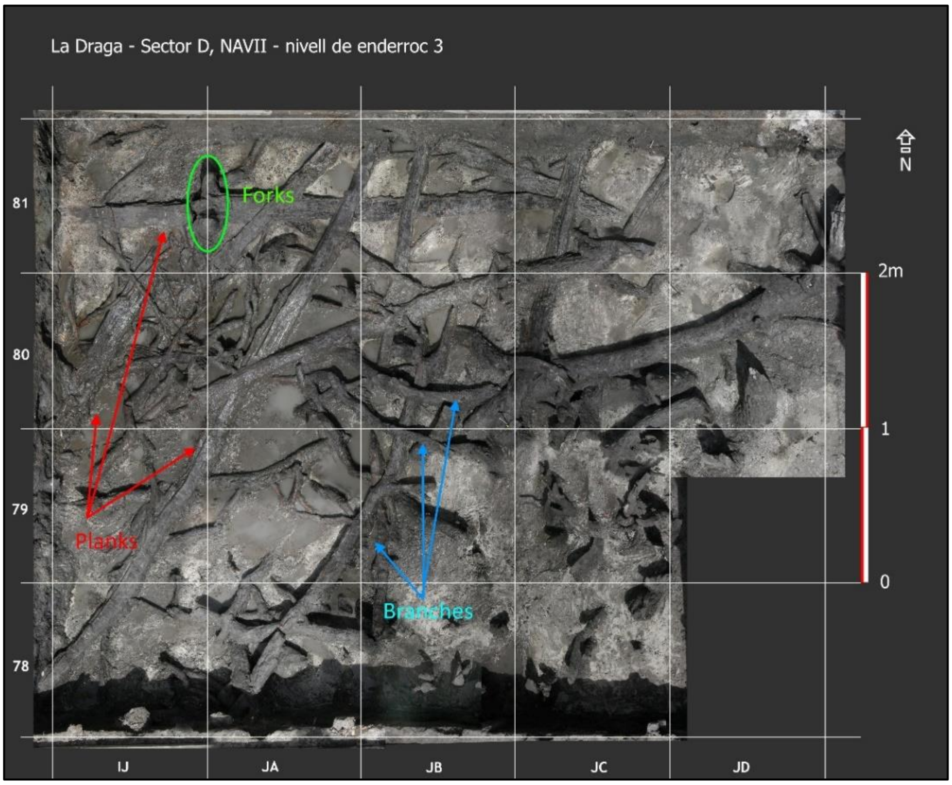


Fig.90: The assemblage in sector D and interpreted as related to the house base plane (photo by I. Bogdanovic).

The characteristics of the base plane are proposed according to:

- The spatial localizations and main features recorded on the architectonical elements from la Draga.
- Deductions made by comparing the archaeological data with the data shown in the chapter on physics (chapter 2.9).
- Data obtained from the analogy with other Neolithic pile dwelling sites.
- Data obtained from the analogy with both ancient and modern pile dwelling sites (chapter 2).

In our reconstruction (Fig.91), the base plane atLa Draga consists of:

- The ground plane (the geological plane).
- The “floor” plane, that includes all those elements meant to sustain the rest of the house.

At La Draga, the ground plane shows no signs of preparation for the house construction. According with our theory, the floor plane consisted of several short forks, a framing and the actual floor. The short forks were inserted directly into the ground plane. These forks were meant to space apart the ground plane from the house, preventing water and moisture from penetrating the structure. The ground plane and the house are spaced 30 cm apart. These forks also worked as support for the framing, made of crisscrossed elements (logs, branches and planks) acting as joists, and supporting the actual floor. The floor seems to have been composed of both long branches and planks, some of which had a triangular section (having been obtained cutting a log into “wedges”). Potential gaps between these elements were probably closed with smaller branches or/and other wooden elements. The following sections will describe the process behind this hypothesis.

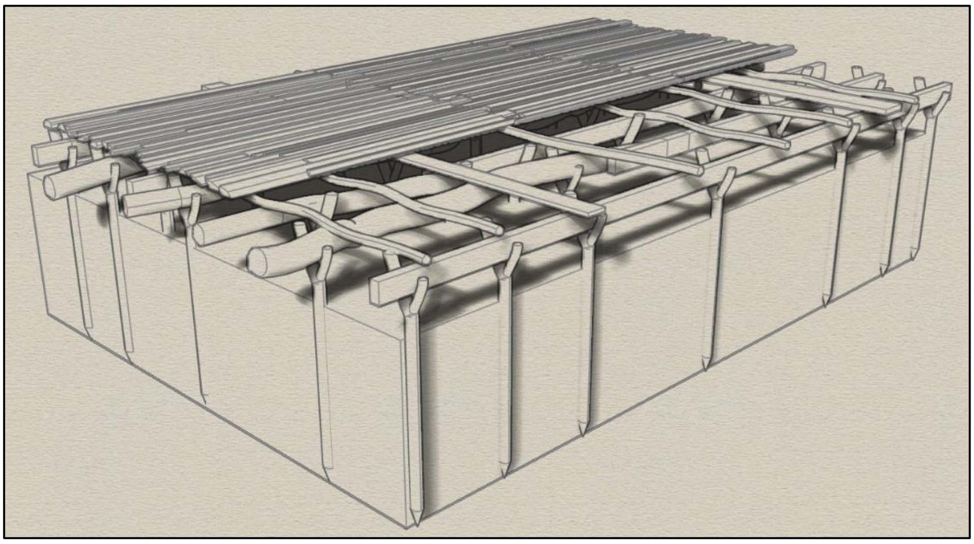


Fig.91: Schematic reconstruction of the base plane at La Draga (image by the author).

4.1.1. Ground Plane

The first element of the base plane is the ground plane. At La Draga, the ground plane corresponds with the geological plane made of lacustrine clay. The ground plane shows no signs of preparation connected with the house construction. According with our general descriptive model the ground plane was natural and not worked. Unlike many other site (e.g. Abtsdorf II-III, Misling II, Shangshan) that of the short forks. , in fact, the piles meant to hold the houses were driven directly into the soil without prior preparation of it (e.g. holes meant to housing the piles). The adhesion/friction between the soil and the piles shafts was probably enough to grant their carrying capacity (see chapter 2.9).

4.1.2. Base Plane Linear Elements – Short Forks

As described in chapter 2.7, are considered linear elements those building components having the necessary material strength to perform structural function. They can provide support for an overhead plane, form a three-dimensional structural frame for architectural space and express movement across space. Row of linear elements could be used to support the floor or roof plane above. How these linear elements affect the texture of a surface will depend on their visual weight, spacing, and direction (Pramar 1973; Ching 2014).

At La Draga, the main linear elements in the base plane, and in the entire house, are the so-called “short forks” (Fig.92), vertical piles inserted into the soil and having their distal extremity characterized by a natural V shape, hence the name “fork”. This V parts was exploited to hold other piles (Fig.94).

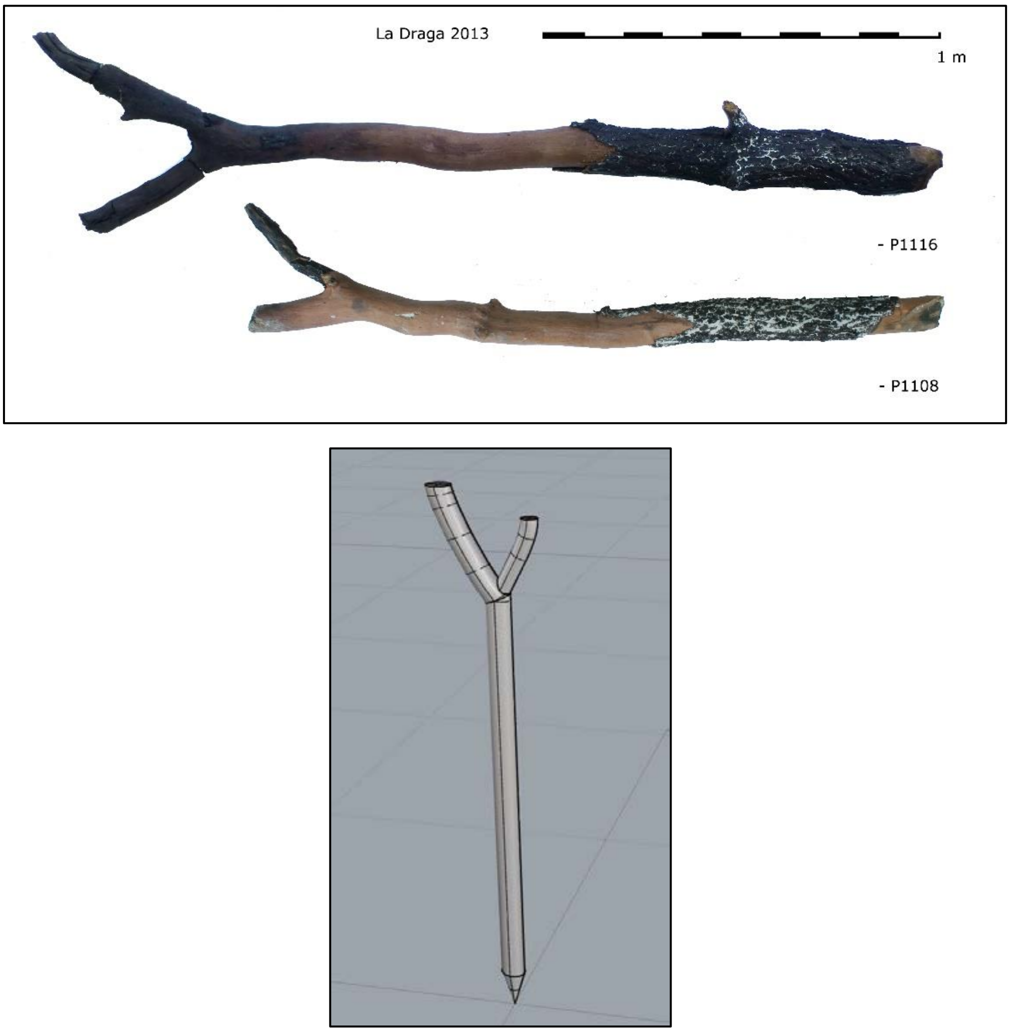


Fig.92. Top: Two of the short forks discovered at La Draga. **Bottom:** 3D schematic solid model of a short fork created to reconstruct the base plane (photo by I. Bogdanovic; 3D model by the author).

The proximal extremity of the fork, instead, was processed in such a way as to have a pointed extremity meant to easily pierce the soil, facilitating the plunging procedure (Fig.93).

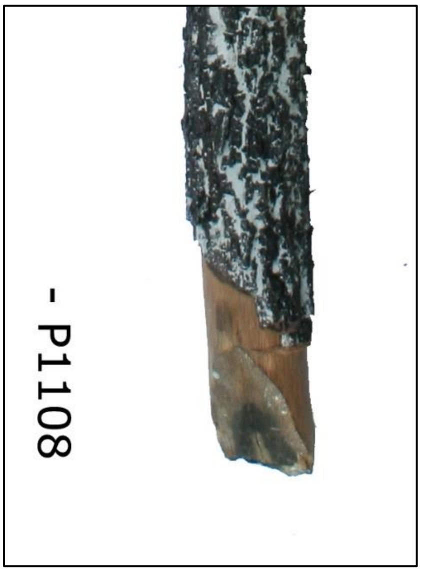


Fig.93: A distal extremity of a short fork from La Draga (photo by I. Bogdanovic).

Archaeologists also found "long forks" (Fig.92). These forks have the same characteristics of the short forks but they are longer, fewer in number and none of them was found in situ. As explained in chapter 3.2 their function was not connected with the base plane. According with our general descriptive model, we can define the forks as natural worked elements.

So far, only 26 complete short forks has been identified. These forks survived because completely submerged under water. In fact, while submerged wood can last for a very long time, the parts not submerged can easily rot as result of wood rotting *fungi* (Filley *et al.* 2001; Fraaij 2007; Srivastava *et al.* 2013) (see chapter 2.11). This means that other piles found inserted into the soil but without top extremity might be short forks, increasing the number of these elements. However, at the present, there is no easy way to know it so only the complete forks have been taken into account. Their average length was 1.37 m of which only 30 cm (including the V end) jutting out from the soil.

Fig.94: A detail of the V shape top extremity of the short fork found in sector D and the connected plank (photo by I. Bogdanovic).

It seems that the short forks had a triple role:

1. To support, together with the ground plan, the entire weight of the house.
2. To ensure the stability of the house structure.
3. To separate the house from the ground preventing water and moisture from penetrating the structure.

Depending on their load transmission and their functional behaviour, the piles can be divided among *end bearing piles*, *friction piles* and *cohesion piles*. Combination of friction and cohesion piles is it also possible.
There are also different way, depending on technology and materials used, to drive a pile into the soil (*driven piles, bored piles, screwed piles*).
So far, at La Draga, there are neither evidences of soil preparation nor evidence of devices meant to enhance the carrying capacity of the short forks. Moreover, the archaeological analysis shown that the lower extremity of the short forks does not rests on a firm ground but, instead, stays "suspended" into the soft layer of lacustrine clay (as the entire fork shaft). On the base of this information, we

can assume that:

- The short forks at La Draga belong to the so-called "*Screwed piles*" group: piles fastened into the ground, much like a screw is fasten into wood. This is an efficient means of installation and coupled with their mechanism of dispersing load, provides effective in-ground performance in a range of soils, including soft soils.
- Regarding the load transmission and the functional behaviour, the short forks at La Draga belong to the "*friction/cohesion piles group*", meaning that their carrying capacity is derived mainly from the adhesion or friction of the soil in contact with the shaft of the fork (Fig.95). These types of pile foundations are commonly known as "*floating pile foundations*".

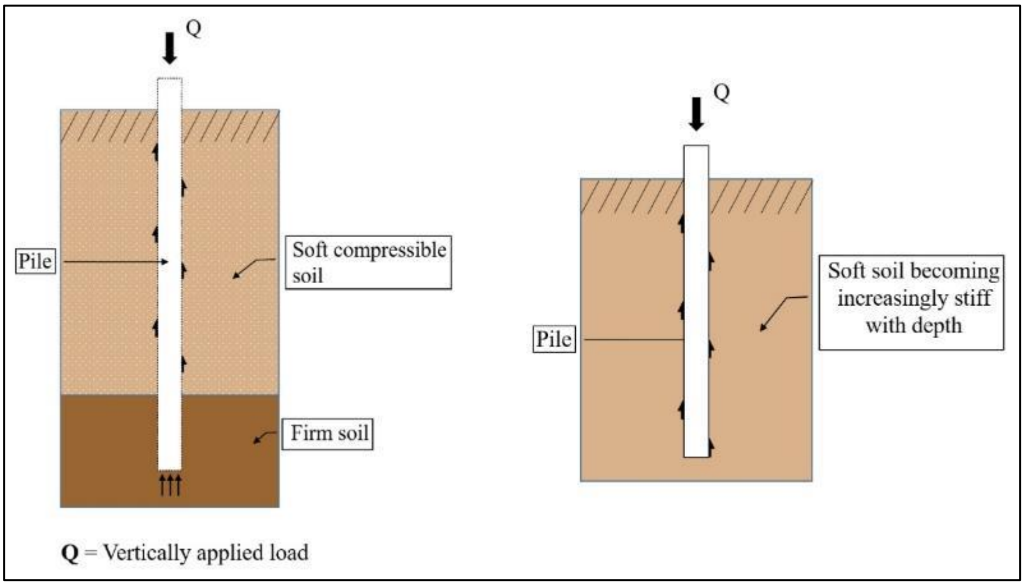


Fig.95: Left: End bearing piles. Right: Friction or cohesion pile (imgae by the author).

Having said that, role 1 and 2 are closely related. The purpose of a pile foundation is to transmit the structure total load to the ground and to resist vertical, lateral and uplift load (Abebe and Smith 2005). This is possible due to two reaction forces in the ground: the *point capacity* and the *shaft capacity*. The bearing capacity for the vertical forces is mainly derived from the *point* *resistance*. The point resistance is the force at the tip of the pile (Sabbe and Serruys 2008). This resistance is caused by the reaction of a bearing stratum in the soil. The shaft capacity is the force that engages the shaft of the pile, caused by the adhesive force of the soil. Therefore, two elements are crucial when it comes down to the base plane (or support structure): the insertion depth and distance among the piles. A pile, in order to develop a good bearing capacity should be driven at least one meter in the bearing soil (Rij 2005). Moreover, if piles are placed too close to each other, the bearing capacity of each pile will reduce. Therefore, the piles should be at least placed 2.5 times the thickness of the pile from each other. As we said, at the beginning, these are the "perfect conditions" needed to build a pile dwelling and we cannot expect to find them perfectly followed at La Draga. Nevertheless, at La Draga the average length of the short forks is about 1.37 m of which 30 cm (including the V end) jutting out from the soil and the rest inserted in it (1.07 m) that is just enough to ensure the bearing capacity.

Instead, regarding the spacing between short forks, the things are more complicated. If we consider only the piles clearly identified as short forks, we can see how the distance among theme far exceed the "perfect" distance required (2.5 times the thickness of the pile), as shown in picture 97. In fact, while the average diameter of the short forks is around 5 cm (the biggest short fork has a diameter of 11 cm; Fig.96), the distance among the forks goes from 30 cm to 2 m meaning that, according to the rule above, the spacing between the short forks is too big.

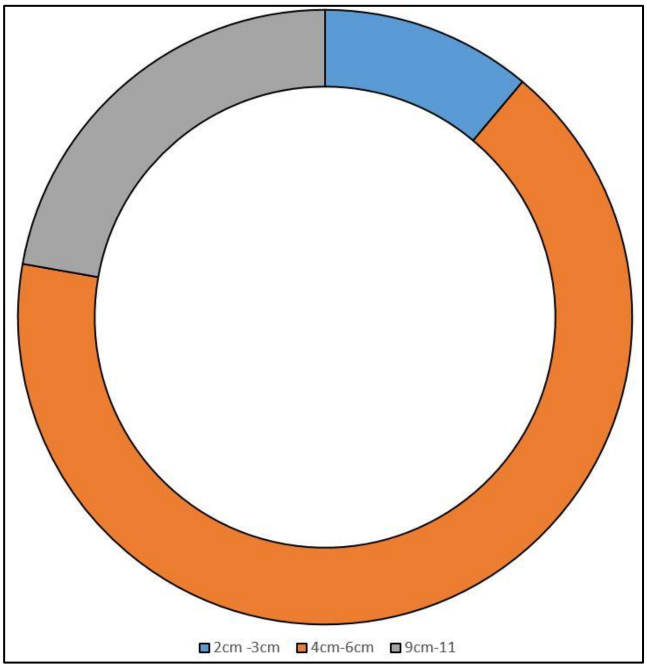


Fig.96: Short forks diameters (image by the author).

However, if we suppose that some of the piles found between the short forks (Fig.97) were indeed short forks (even if at the moment we cannot be completely sure of it), then the needed spacing seems to be match, as shown in the pictures below.

The diameters of the short forks seem to corroborate this hypothesis. In fact, they seems to be too small to hold a building by themselves. If we take into account the other Neolithic pile dwellings, where the diameters of the piles composing the base plane are known, we can see how pile of 5 cm diameter exists but are always combined with piles with a bigger diameter (e.g. Clairvaux 7.5-14.5 cm; Maharki prekop 5.8-26 cm; Korküla 20 cm; Serteya II 8-20 cm ; Veksa III 5-15 cm; Shangshan 25-40 cm etc.) Therefore, we can assume that some of the piles found around the short forks, even if their upper extremities were missing, were short forks too (or, at least, elements of the base plane).

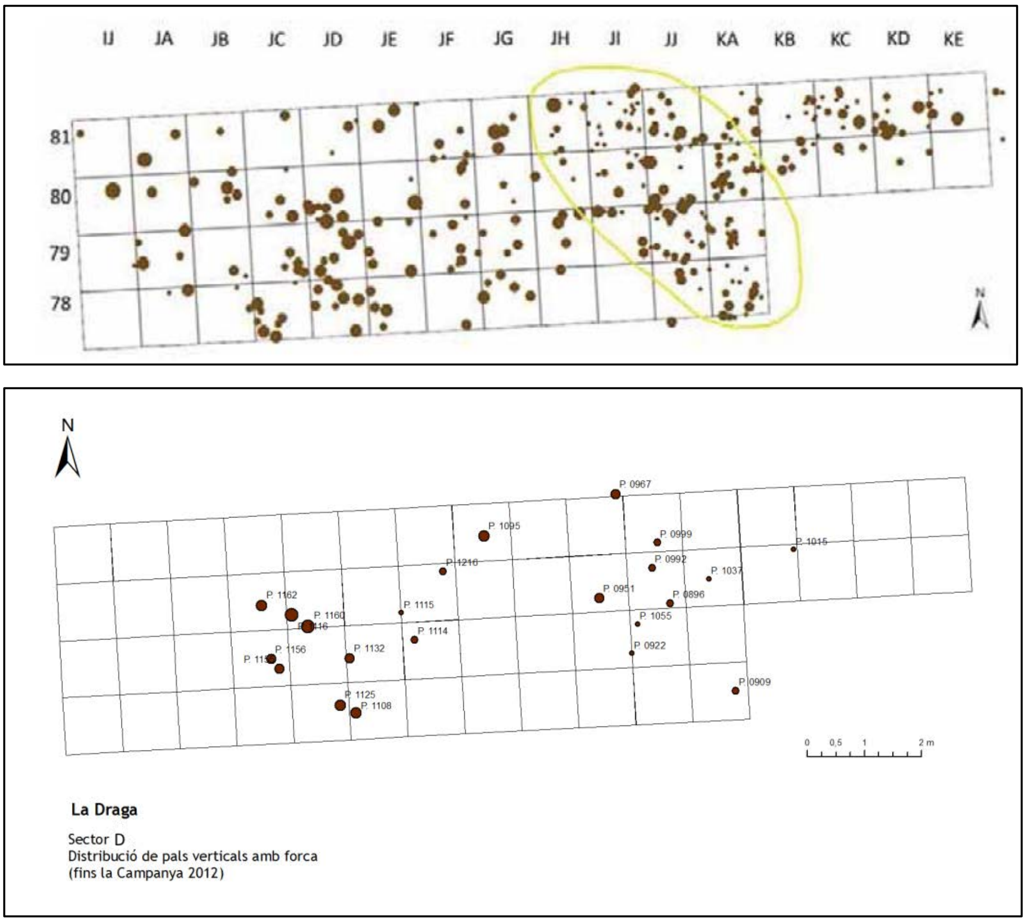


Fig.97. Top: The vertical piles found at La Draga in sector D. **Bottom**: The piles identified without a doubt as short forks (images by I. Bogdanovic).

The diameters of these "pointless" vertical piles range from 2 cm to 16 cm, which are completely in line with the diameters of those piles composing the base planes in other Neolithic sites. Instead, regarding the number of forks necessary to hold the house, it usually depends on different factors like the pile material and its properties, their forms, the composition of the soil and its proprieties, the weight of the house structures, the physic forces acting on the structure, their intensity etc. All these aspect are carefully taken into consideration in modern architecture but it is very likely that much of them were unknown to Neolithic people. In some cases, archaeologists found alignments of piles that helped to define the number of elements used to build the base plane. Even so, it is possible that in some cases "backup" piles, needed to prevent the house from sinking or bending, went missing over time, therefore knowing the exact number of piles that were used is a very difficult task.

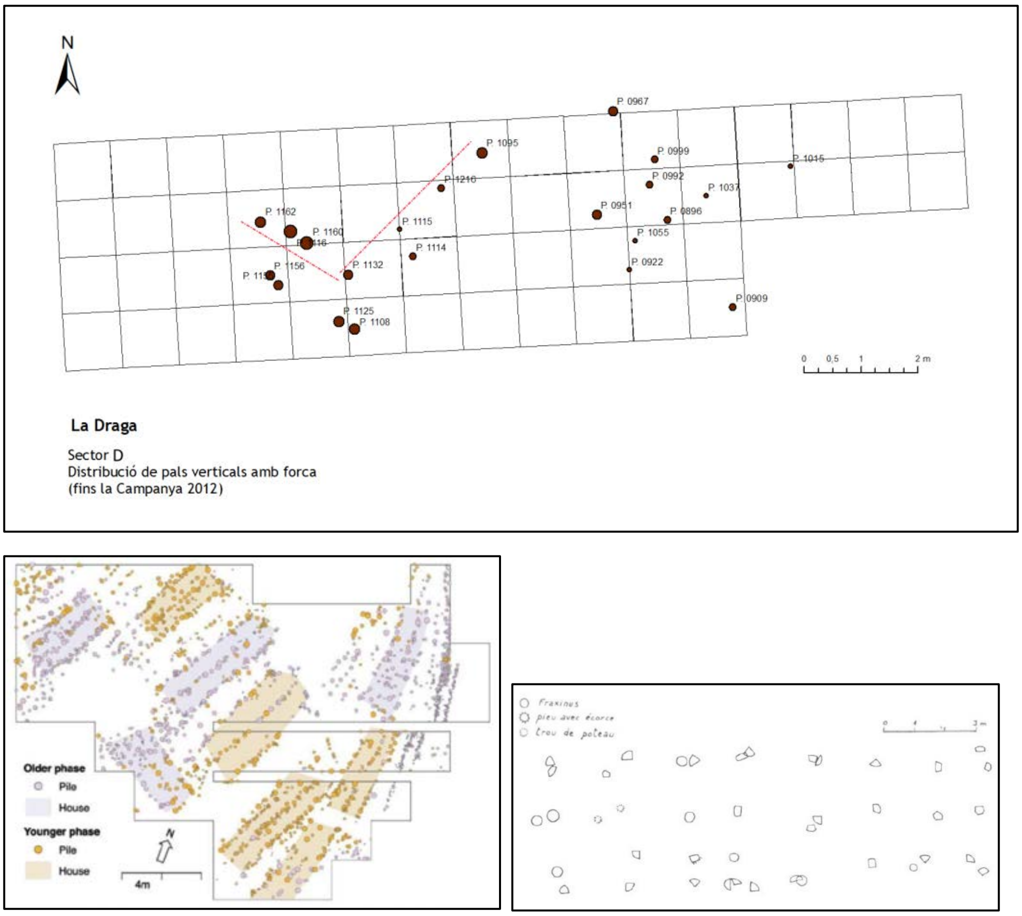


Fig.98: The alignments identified so far at La Draga in sector D and the alignments found at Maharki prekop (left) and Clairvaux (right) (images by I. Bogdanovic).

At La Draga the situation is much more complicated. In fact, there are only two probable clear alignments of short forks (P1162, 1116, 1160, 1132; P1132, 1115, 1216, 1095; Fig 98). Taking into account the other vertical piles, the situation gets better but the difference with the clear alignments found in other sites (Fig.98) is striking (Clairvaux, Niederwil, Sutz-Lattrigen, Keutschacher See etc.). Moreover, as said before, because the number of the piles to use depends on so many different factors, a comparison with the other sites, in order to assume a probable number, cannot be made. This means that, at the moment, we have no way to determinate the exact number of forks they used to build the base plane. In our reconstruction, using different distances, we used a total of 40 short forks (Fig.99).

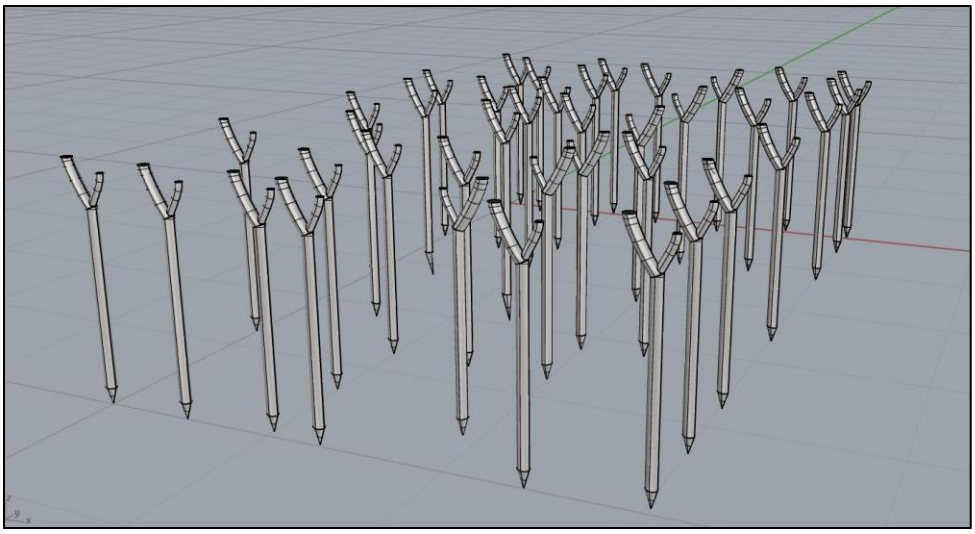


Fig.99: 3D model built in Rhino 5 ad representing the short forks composing the base plane at La Draga (model by the author).

Even if the evidence about the alignments are few we can assume that the short forks were positioned in such a way that they can easily support the above framing as the evidences found in sector D seems to indicate (Fig.101).

Finally, the third role of the short forks was to separate the house from the ground preventing water and moisture from penetrating the structure. As we already said, at La Draga the short forks protrude from the ground plane of 30 cm (Fig.100). This is, of course, a typical aspect of the pile dwellings meat to separate the interior of the house from the soil preventing water and moisture from penetrating the structure and/or keeping the inhabitants safe from wild animals. The site of Abtsdorf II and III show a similar distance between soil and house floor: 20-30 cm.

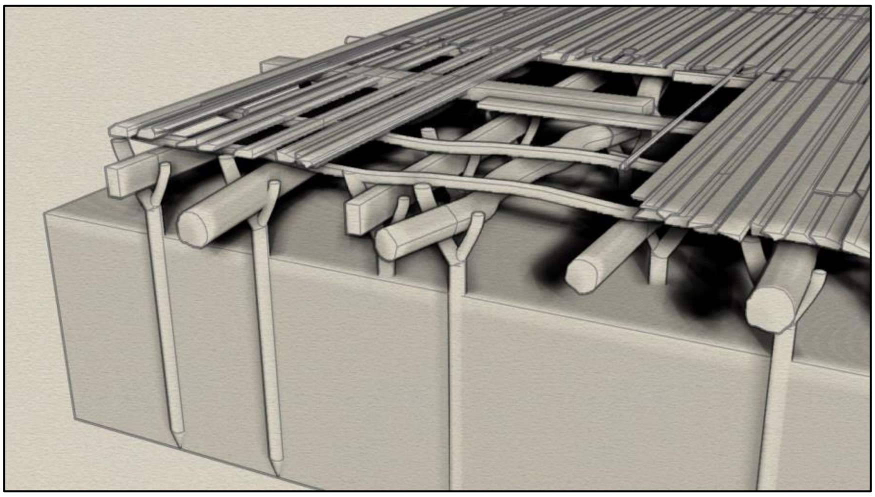
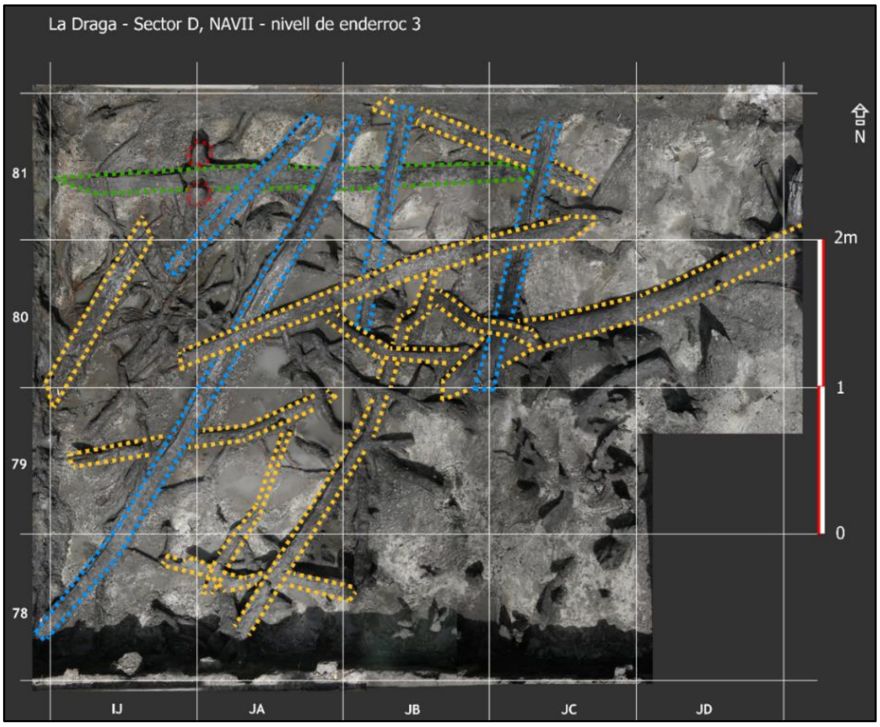


Fig.100: Detail of the base plane 3D model showing the gap between soil and floor (model by the author).

4.1.3 Base Plane Linear Elements – Framing

Secondary linear element of the base plane is the framing. The framing, probably composed by crisscrossed planks, small trunks, piles, and braches, rested on the short forks.



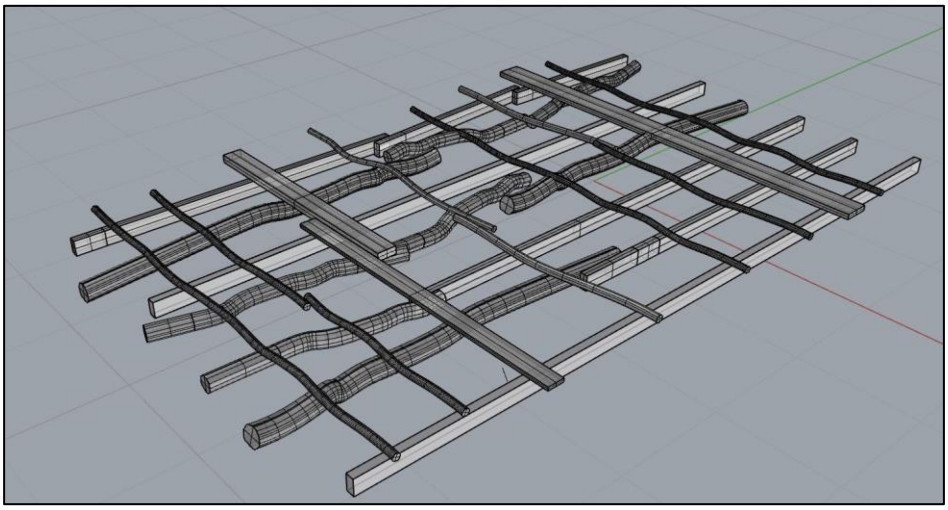


Fig.101. Top: Sector D, possible wooden element composing the base plane (photo by I. Bogdanovic). **Bottom**: 3D model built in Rhino 5 ad representing the possible aspect of the base plane framing system (model by the author).

This framing was meant both to hold the actual floor and functioning as support for the house structure. The archaeologists at La Draga gathered evidences about this assemblage in sector D, where they found the already mentioned plank (3.50 m long) inserted into a short fork and lying parallel to the soil (Fig.101,102). Four other planks laid, perpendicularly, on this plank, probably in their original location.

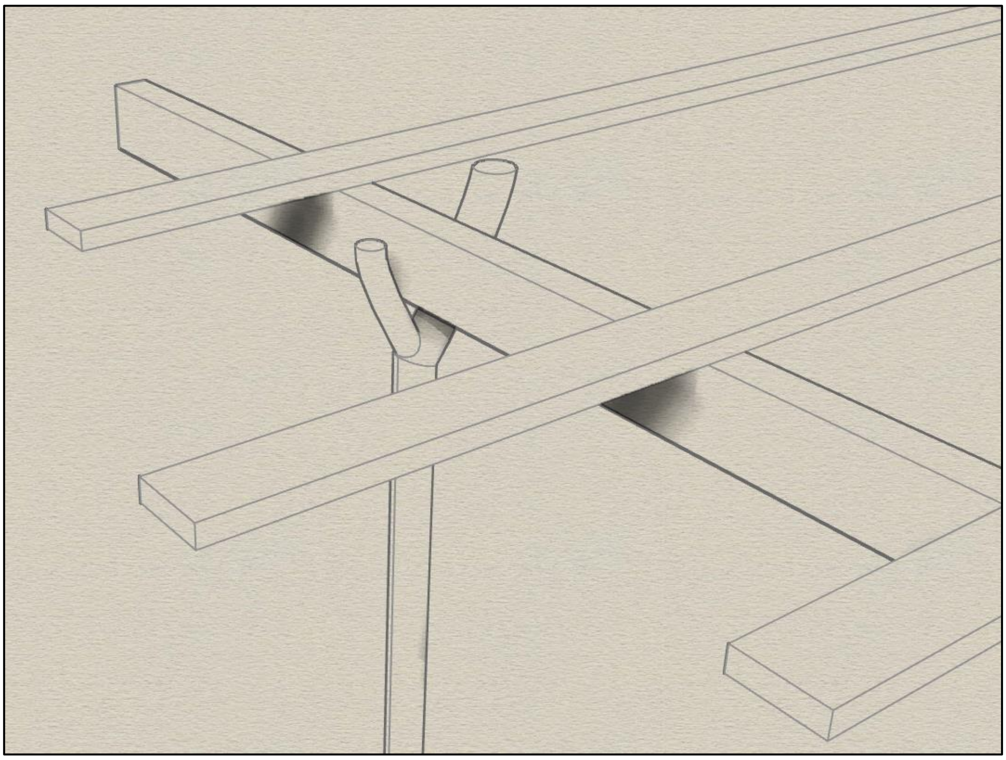


Fig.102: The assemblage found in Sector D and its reconstruction (photo by Bogdanovic; model by the author).

However, there is few information about the horizontal wooden elements interpreted as parts of the framing. The longest elements interpreted as being part of the framing was 6.27 m long. Its length has been used as maximum length for both the framing and the platform/floor while, for the width, there is no direct information. To compensate, we deduced it using the intersection between those elements forming the overhead plane (the lateral walls) and the base plane as explained in section 4.2.7. The result seems to indicate an overall width of 3.50 m.

Based on what we described in chapter 2.9. (*The Physic behind the Pile-Dweling Architecture*) we can assume that the framing and the flooring acted as a pile cap (Fig.103).

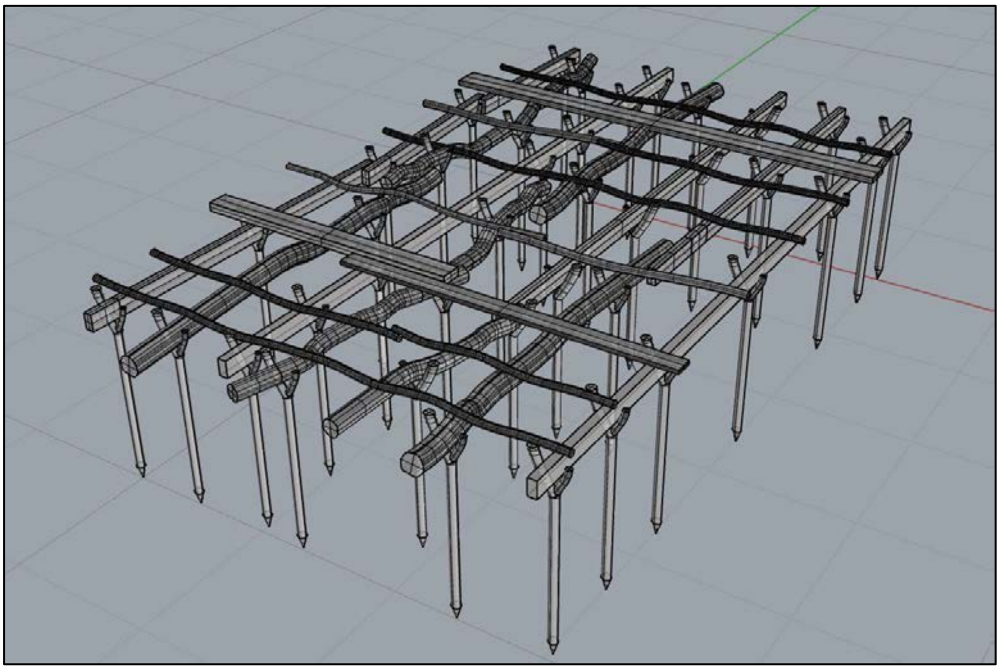


Fig.103: 3D model built in Rhino 5 ad representing reconstructive hypothesis for the short forks and the framing assemblage (model by the author).

A pile cap has the function of spreading the load from a compression or tension member onto a group of piles so that, as far as possible, the load is shared equally between the piles (Fig.104).

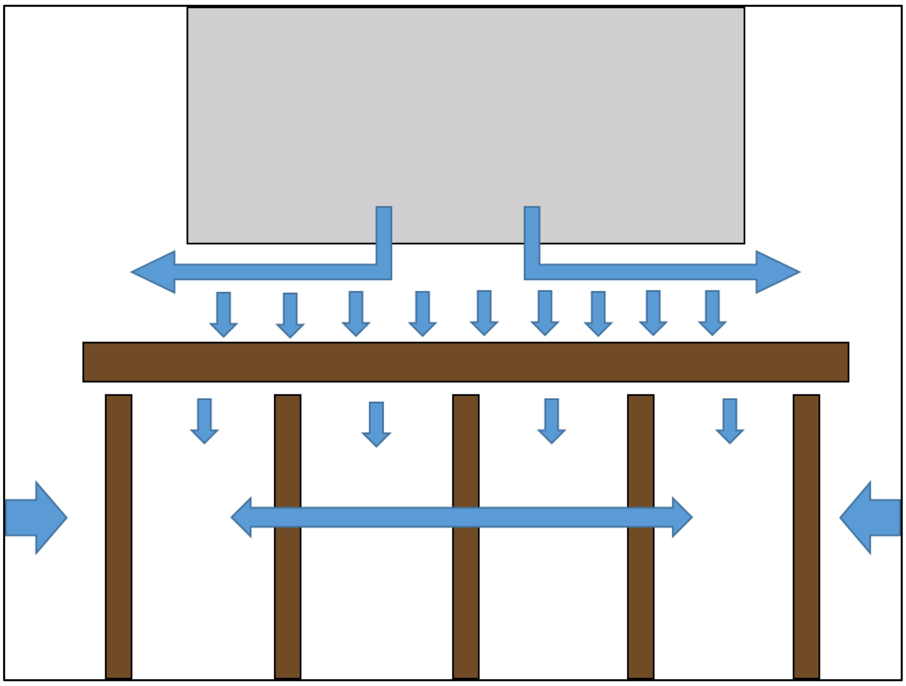


Fig.104: The image represents the forces (blue arrows) acting on the base plane (image by the author).

The pile cap also accommodates deviations from the intended positions of piles, and by rigidly connecting all the piles in one group, the ill-effects of one or more defective piles are overcome by redistributing the loads (Tomlinson and Woodward 2014).

The actual floor was made, probably, of planks and branches/piles closing possible gapes between the first ones (Fig.106). These planks had triangular section and were obtained by splitting trunks in “slices” using stone tools and wooden wedges (Fig.105). The floor can therefore been described as composed of natural elements both worked and not worked.

Fig.105: One of the plank found at La Draga (photo by O. López).

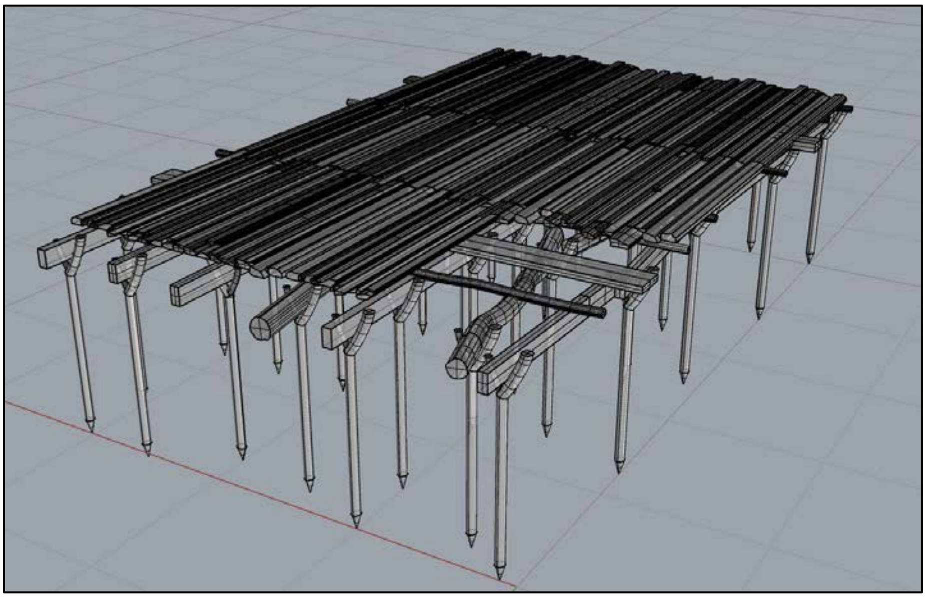


Fig.106: 3D model built in Rhino 5 ad representing the base plane reconstructive hypothesis (model by the author).

An example of floor made using planks can be found in some the Bajau Laut (Malaysia) houses.

This type of pile cap is documented in many other pile dwelling sites for example at Serteya II, Clairvaux, Hornstaad-Hörnle IA, Maharski prekop, Torwiesen, etc (Fig.107,108). According with our general descriptive model, the base plane framing at La Draga was composed of natural elements both worked and not worked.

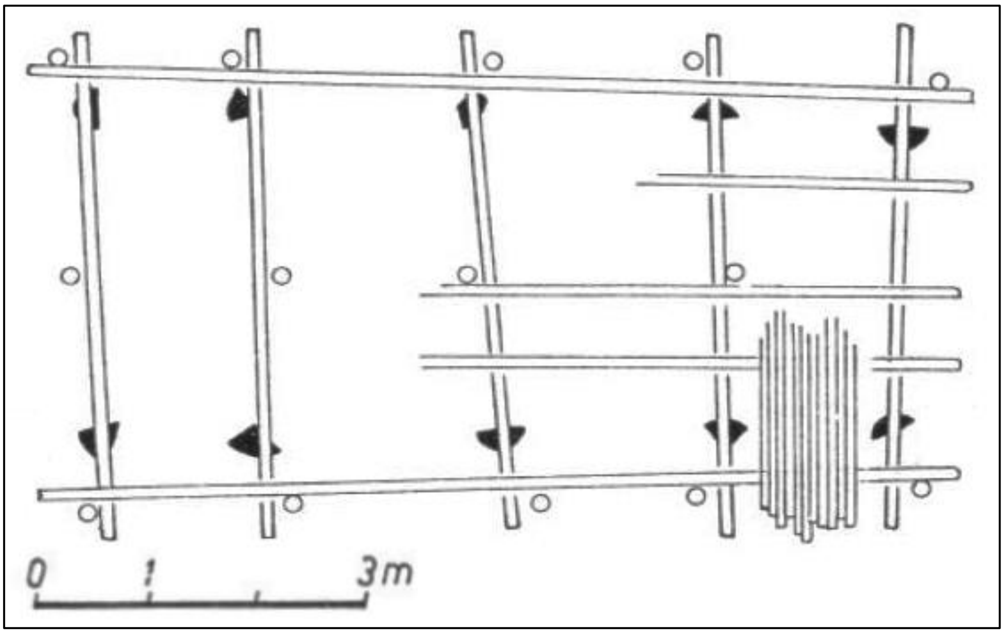


Fig.107: Clairvaux, station II. Reconstructive hypothesis of the base plane (Pétrequin 1988).

Fig.108: Rests of the base plane framing structure at Torwiesen (Schlichtherle 2002).

As shown by anthropological comparison, the use of a pile cap made up of framing ad floor is still one of the most used in pile dwelling settlements (and not only) especially if the constructions are made of wood. We can find this architectonical solution being used in the traditional Malay houses (Fig.109), the houses of the Aka people, in the houses on river Fenghuang in China, in the house of the Badjao people (Philippines) and even in modern timber house in Norway.

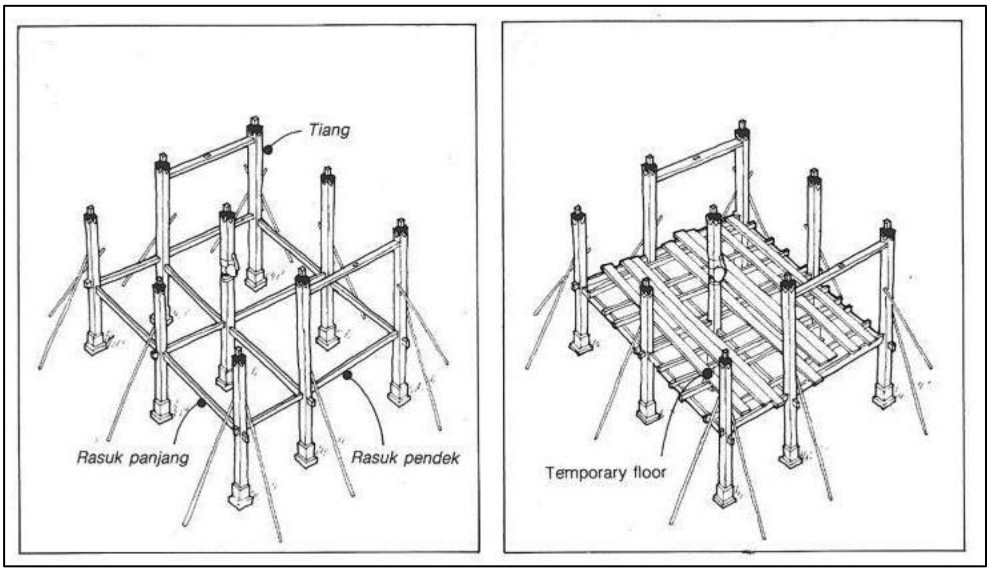


Fig.109. Top: The Erection of Basic Traditional Malay House Form (Yuan 1987).

4.1.4. Base Plane Dimensions

The only direct data that we have about the base plane dimensions come from the short forks and their measures. They have an average length of 1.37 m. and they were inserted into the soil, jutting out only for c. 30 cm. For the overall dimension of the base plane, at the current state of the investigation, there is no direct information. Therefore, we tried to "fill" this gap using the few certain data we had. To postulate the overall length of the base plane, then, we used the size of the longest wooden elements seemingly connected with it. This element is 6.27 m long and it is probably part of the architectonical assemblage found in sector D (specifically it is one of the four planks lying on the one plank connected with the short fork) (Fig.110). Therefore, as I said, we postulated that also the overall length of the base plane might be of about 6.27 m (Fig.111). This measure is similar to the house length observed in other Neolithic pile dwellings: Misling II 3 – 4 m; Torwiesen 3 – 7 m; Serteya II 7 m; Maharski prekop 8 – 10 m; Sutz-Lattringen 8 – 12 m; Niederwil 8 – 12 m; Clairvaux 13 m; Shangshan 14 m; Hemudu 23 m.

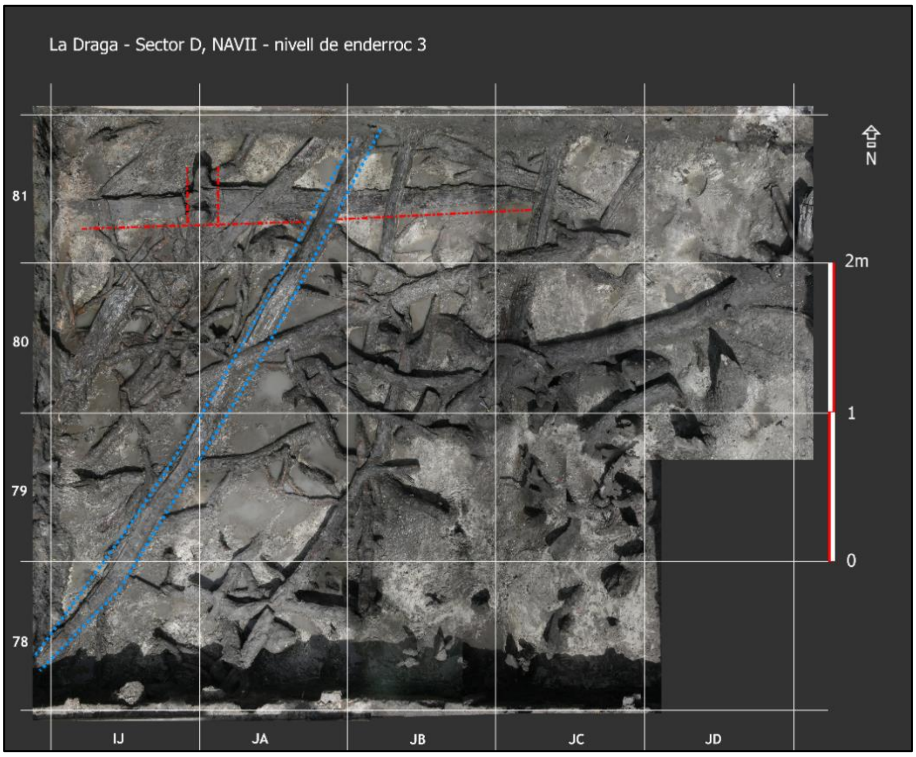


Fig.110: The assemblage found in sector D: the red line indicates the forks and the plank stuck into its V-shape extremity. The blue line indicates a long wooden elements lying perpendicularly to the plank. This element and the plank would be part of the base plane framing made of criss-crossed elements (photo by I. Bogdanovic; drawings by the author).

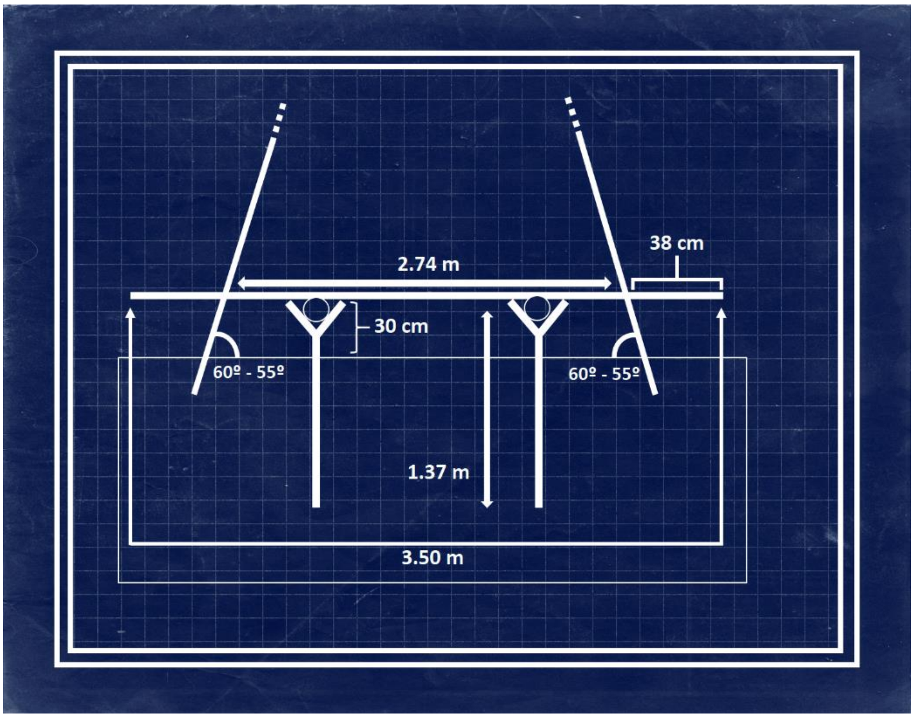


Fig.111: Base plane dimensions (blueprint by the author).

Regarding the overall width of the base plane, we have no direct information too. To postulate the base width, then, we used the inclination of the elements composing the roof pitches, or overhead plane, (60-55º) and the base plane high (1.37 m) (Fig.111).

With these data, we determined the points of intersection between these two planes. The distance between these two points would indicates the interior width of the house: 2.74 m. However, we still do not known the overall width. Now, the only element that seems to be clearly related with the base plane is the one plank found stuck into the V-shape extremity of the short fork of the assemblage found in sector D and measuring 3.50 m. We can consider this element as maximum width of the base plane. Then the platform width would be 76 cm wider than the house, that is c. 38 cm each side. This aspect seems to coincide with both archaeological and ethnographical data shown that, sometime the platform composing the base plane could be bigger than the house itself. In addition, the overall dimension of the base plane seems to coincide with the width of pile dwellings coming from other Neolithic pile dwelling sites: Maharski prekop 3.5 – 4.5 m; Serteya II 4.5 m; Torwiesen II 3 – 5 m; Clairvaux 4 m; Sutz-Lattringen 4.5 – 5 m; Niederwil 5 m.

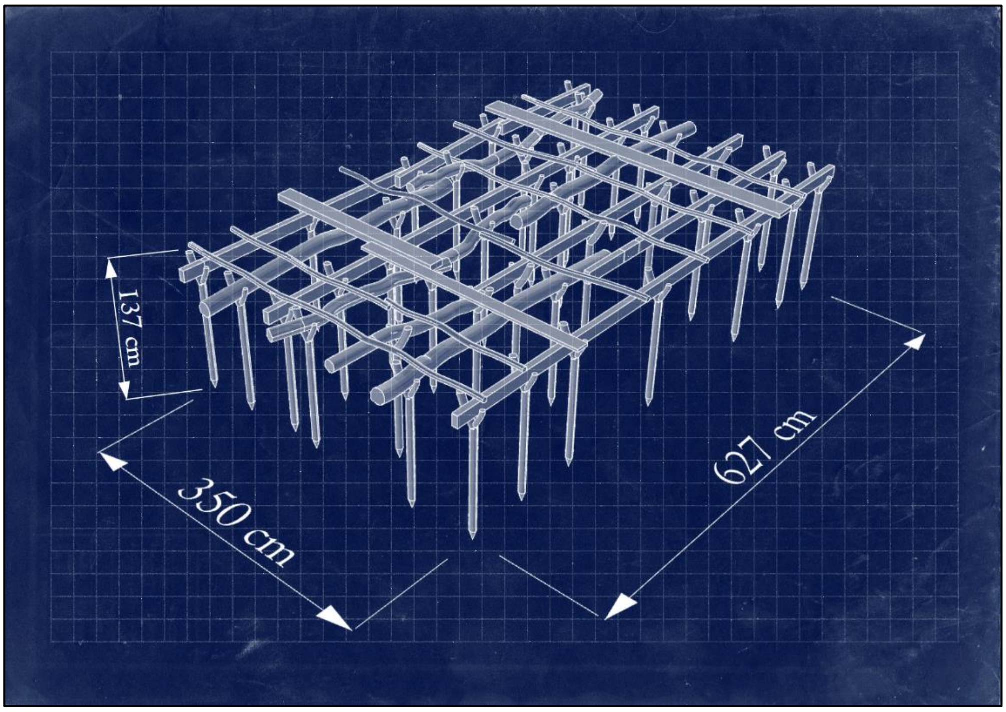


Fig.112: Base plane reconstruction and dimensions (blueprint by the author).

4.1.5. Base Plane Connections

The short forks represent the only certain joint elements identified during the excavations. As said before, their V-shape extremities were meant to house the framing elements. Although both rolls of lianas and ropes made of thin twisted fibres have been recovered at La Draga (Piqué *et al.* 2016) (Fig.113), there are no evidences that they were used as connections to tie together the different elements composing the base plane. This could only mean that:

1) The base plane elements would have simply lean against each other.

2) Lianas and ropes were indeed used to connect the various parts of the base plane even if so far we have no direct evidence of it.

Fig.113. Top: A piece of rope from La Draga. **Bottom:** A lianas bundle found at La Draga (images from Bosch *et al.* 2006).

Both archaeological and ethnographical analogy seem to indicate the second option. Evidences of lianas and/or ropes tying together the various elements of the base plane have been collected from several archaeological pile dwelling sites (e.g. Serteya II, Clairvaux, Sutz-Lattrigen, Riedstation, Hornstaad-Hörnle IA etc.). However, these evidences are often fragmentary and give us little information. Ethnographical analogy, on the other hand, display both the use of natural fibres (in different forms) as connection and can give us an indication about how these connections were used in the past. All the modern pile dwellings taken into account shown the same device: the vertical piles of the base plane where tied together with the element composing the framing, preventing lateral displacement and making the entire structure more resilient. The elements making up the actual floor are either tied together and to the framing or simply leaned on it. Some examples are the house Sri Ma houses (India) (Fig.114), the Darai houses (Irian Jaya, Indonesia) (Fig.115), the Bajau Laut houses (Malaysia) etc.

Since this configuration can be observed also among the most "simpler" modern pile dwellings we can assume, for ethnographical analogy, that something similar was also used at La Draga.

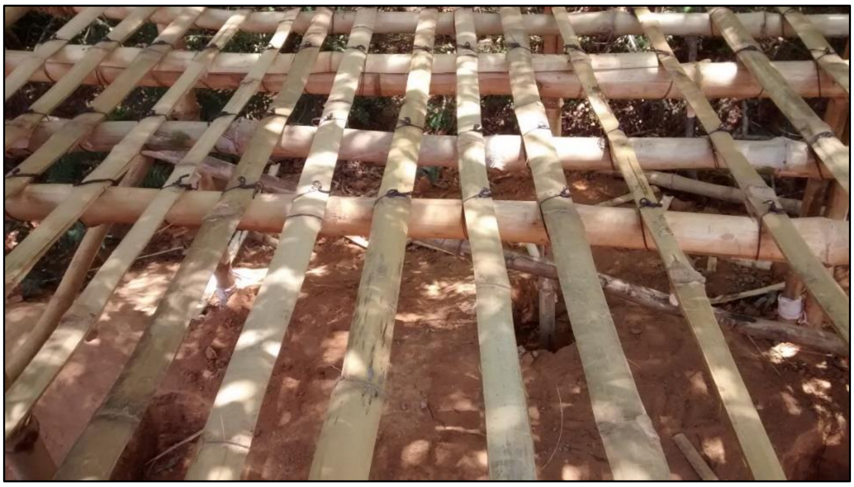


Fig.114: Two details of the Sri Ma (Auroville, India) house base plane and its connection system (www.auroville.org)

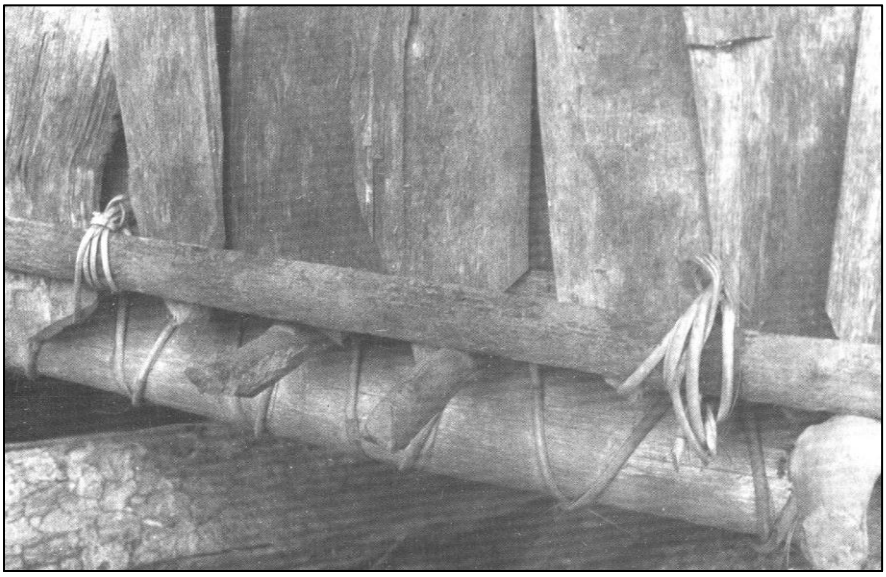


Fig.115: Darai house (Indonesia). The base plane and vertical plane elements are connected using ropes made of natural fibres (Pétrequin 1988).

4.2. OVERHEAD PLANE OF THE DRAGA HOUSE

As described in chapter 2.7, the overhead plane is the complex of elements meant, whatever their form, materials and arrangement, to offer protection to the interior of the building. The overhead plane can be either the roof plane that shelters the interior spaces of a building from the climatic elements, or the ceiling plane that forms the upper enclosing surface of a room. The material, geometry, and proportions of its structural system and the manner in which it transfers its loads across space to its supports, in turn, determine the form of the roof plane. The overhead plane can visually express how the pattern of structural members resolves forces. The roof plane can be hidden from view by the exterior walls of a building or merge with the walls to emphasize the volume of the building mass. It can be expressed as a single sheltering form that encompasses a variety of spaces beneath its canopy, or comprise a number of hats that articulate a series of spaces within a single building. Finally, the overhead plane can be the major space-defining element of a building and visually organize a series of forms and spaces beneath its sheltering canopy. The ceiling plane of an interior space can reflect the form of the structural system supporting the overhead floor or roof plane. Since it need not resist any weathering forces nor carry any major loads, the ceiling plane can also be detached from the floor or roof plane and become a visually active element in a space (Pramar 1973; Ching 2014). As said before, the overhead plane can be either the roof or the ceiling.

Roof plane:

- Can be single or multiple.
- Can extend outwards as overhang.
- Can be elevated to allow breeze to pass through.

Ceiling plane:

- Can reflect the form of the structural system.
- Can be detached from the roof plane, suspended, underside of an

overhead.

- Can be lowered/raised to articulate spaces.
- Can be manipulate to define and articulated spaces.
- Can be manipulated to define and articulate zone of spaces.

The overhead plane of a simple timber house is generally composed of one ridge beam, several purlins, rafters, and two tie beams. Usually, among the purlins and the rafters, there are two principal purlins and four principal rafters: heavier than the others, they play an important role for the stability of the roof. The interconnection of all these elements forms the roof framing meant to support the covering on both the roof pitches (Ching 2014; Pramar 1973).

The hypothesis for the overhead plane of the pile dwellings of La Draga is based, firstly, on the presence of vertical, horizontal and tilted architectural wooden elements: the so-called "long forks", branches and beams lying on the natural soil.

The characteristics of the overhead plane are proposed according to:

- The spatial localizations and main features recorded on the architectonical elements from la Draga.
- Deductions made by comparing the archaeological data with the data shown in the chapter on physics (chapter 2.9).
- Data obtained from the analogy with other Neolithic pile dwelling sites.
- Data obtained from the analogy with both ancient and modern pile dwelling sites (chapter 2).

At La Draga, the overhead plane of the houses corresponds with the roof plane. So far, no direct evidence of ceiling plane has been found however, its presence can be discarded since, up to now, no other Neolithic pile dwellings settlement seems to possess this element. Moreover, also the pile dwellings taken into account for the ethnographical analogy show no trace of the ceiling plane (with the exception of the Norwegian houses) (see chapter 2).

In our hypothesis, the overhead plane structure includes: an horizontal ridge beam supported, at least, by two main vertical long forks acting as main posts; several tilted elements plunged into the soil and acting as rafters of which at least four acting as principal ones; several horizontal elements acting as purlins and connected with the tilted elements creating a criss-crossed frame (Fig.116).

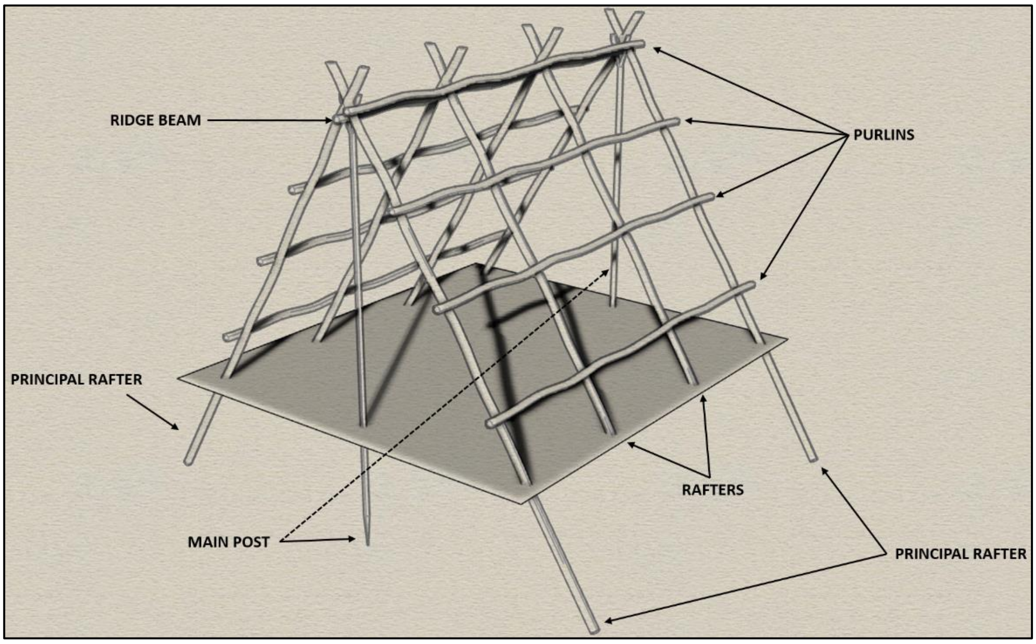


Fig.116: The components of the house overhead plane at La Draga (image by the author).

This assemblage create the peculiar form known in architecture as A-shape house.

Using our general descriptive model, we described the overhead plane as made of natural elements, both worked and not worked, and as multifunctional since we postulated that it acted both as roof and lateral walls.

The following sections will describe the process behind these hypotheses.

4.2.1. Overhead Plane Linear Elements – Long Forks

As described in chapter 2.7, are considered linear elements those building components having the necessary material strength to perform structural function. They can provide support for an overhead plane, form a three-dimensional structural frame for architectural space and express movement across space. Row of linear elements could be used to support the floor or roof plane above. How these linear elements affect the texture of a surface will depend on their visual weight, spacing, and direction (Pramar 1973; Ching 2014).

At La Draga, the main linear elements in the overhead plane are the so-called "long forks", long piles having their distal extremity characterized by a natural V shape, hence the name "fork" (Fig. 117). This V parts was exploited to hold other piles. The proximal extremity of the fork, instead, was processed in such a way as to have a pointed extremity meant to easily pierce the soil, facilitating the plunging procedure.

Fig.117: Two examples of forks from La Draga (photo by I. Bogdanovic).

However, no long fork has been found in its original position: all the long forks identified so far were lying on the soil.

We use the term "long forks" to distinguish them from the "short forks". Short forks have the same characteristics of the long forks but are shorter, larger in number and the majority of them was found still inserted into the soil in its their original location.

So far, only 9 complete long forks has been identified and their length ranges between 2 and 3.12 m (while the average length of the short forks is 1.37 m) (Lopez 2015).

These forks survived because completely submerged under water. In fact, while submerged wood can last for a very long time, the parts not submerged can easily rot as result of wood rotting *fungi* (Filley *et al.* 2001; Fraaij 2007; Srivastava *et al.* 2013) (see chapter 2.11). This means that other piles found inserted into the soil but without distal extremity might be also long forks, increasing the number of these elements. However, at the present, there is no easy way of knowing, therefore only the complete forks have been taken into account.

Even if these long forks were found lying on the soil the analysis of their shaft, reveals that they were plunged into the soil. The analysis of the longest fork found (3.12 m) shown that its proximal part presents characteristics different from the rest of the shaft (e.g. coloration), probably as results of being inserted into the soil. The part plunged into the soil was 52 cm long.

Due to their superior length and the fact that they were found lying "on" the soil, rather than plunged "into" the soil, we postulate that their role was different from that of the short forks. Our hypothesis is that these long forks were used as main posts with the task of holding the ridge beam. They probably get through the base plane to be plunged into the soil. In order to hold the ridge beam in place, at least two main posts are needed, otherwise the ridge beam falls. This solution, with a variable number of main posts, has been found at Clairvaux (Pétrequin 1988), Torwiesen II (Schlichtherle and Hohl 2002; Dosedla 2016), Hornstaad Hörnle (Fig.118) (Jocomet and Brombacher 2005), Abtsdorf II and Abtsdorf III (Czech 1977, 1982; Ruttkay 1982; Hirmann 1999), Misling II (Ruttkay *et al.* 2004), Maharski prekop (Bregant 1974, 1975; Velušček 2013), Serteya II (Mazurkevich and Dolbunova 2011; Mazurkevich 2013; Kulkova *et al.* 2015), Veksa (Nedomolkina 2006; Nedomolkina and Piezonka 2010), Dispilio (Touloumis *et al.* 2003).

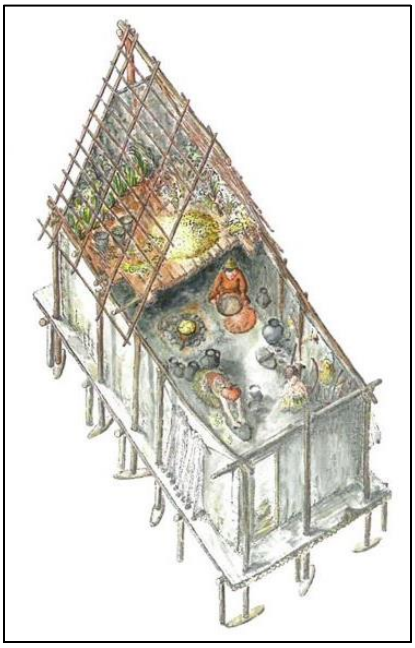


Fig.118: Reconstruction of the Hornstaad-Hörnle IA settlement (Verlag 2016).

Also ethnographical examples show the diffusion of this device like the Bajau Laut houses, the Hetin-Sota houses on Lake Nokoué, the Paniduria Nocte houses, the Sumbawa houses (Fig.119), the Akha houses, Badjao houses and many other.

Fig.119: Sumbawa house, Donggo tribe (Indonesia) (http://muhamadyasid.blogspot.com).

The diffusion of this system in both archaeological and modern pile dwelling sites and the presence of similar elements at La Draga, seem to support our reconstructive hypothesis. However, we have no evidence about the exact number of main posts used. The number depends on a variety of factors as the dimension of the ridge beam, the shape of the main posts, their materials, the techniques used to build them, the local climate and the forces acting on the house (wind, snow etc.). However, as said before, at least two main posts are necessary to hold a ridge beam in place (in a double pitched roof). The Sumbawa houses (Indonesia) and the "Shaman Hut" on Lake Ledro (Italy) (Fig.120) that are, among the other things, the two kind of houses whose shape resemble the most our reconstruction, had only two main posts holding the ridge beam: one on the front and one on the back side of the house.

Fig.120. Top Sumbawa house (Indonesia) (http://trip-suggest.com). **Bottom**: the "Shaman Hut" on Lake Ledro (Italy) (www.stock.adobe.com).

This means that, even if we do not know the exact number of main posts used at La Draga, they should be at least two. Therefore, instead of postulating a random number of main posts we decided to use the minimum number required, positioning a main post on the front side of the house and one on the back. The distance between these two elements probably also defined the length of the interior space of the house.

However, since the long forks were found lying on the soil and since was impossible to identify the related postholes, there are no direct evidences to estimate this distance. All we can do is making assumption on the base of the other data we have. First, as said in section 4.1, we hypothesized that the overall length of the base plane was 6.27 m. Since is probable that some space was saved on the front side to undertake different activities the house interior was presumably smaller than the platform. Some example of this arrangement can be observed in many modern pile dwellings as those belongings to Bajau Laut, or those at the Irrawaddy Delta (Myanmar), or at Kri Island (Indonesia), Lake Nokoué, Chin state (Myanmar) Zancudos (Myanmar), Port Quepos (Costa Rica), Badjao.

Archaeologically, we have small information from other Neolithic pile dwelling settlements since frequently is not specified if the width of the platform coincides with the interior width of the house.

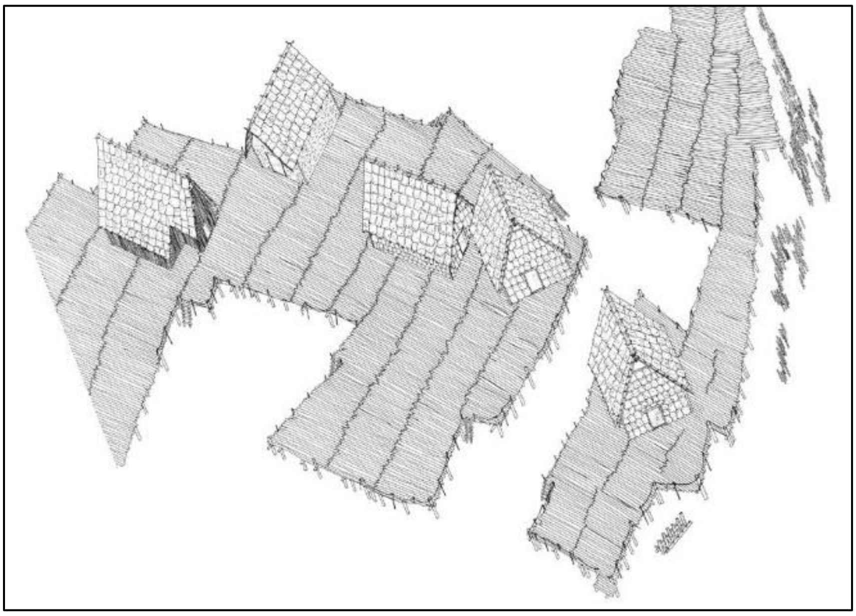


Fig.121: Maharski prekop. Settlement reconstruction (Bregant 1996).

However, sites as Sutz-Lattrigen, Maharski prekop (Fig.121) and Dispilio shown the presence of bigger platforms on which the houses were located.

These platforms provided a workspace for different activities. The dimensions of this area, both in archaeology and ethnography, vary widely. We can imagine that it had to be large enough to allow at least one person to work "comfortably". Looking at the ethnographical examples, it seem that the length of these areas range between 1 and 5 m of, while the width usually match the house width or it is just little bigger. Therefore, we can assume that also at La Draga the workspace in front of the house could have a length ranging probably between 1 and 5 m and matching, or marginally exceeding the house width.

Considering all these data, we postulated that the distance between the two long forks acting as main post could be of 3.00 m. This means that, if the rear wall was perpendicularly aligned with the rear side of the base plane, the front area for the activities should be c. 3.27 m long (Fig.122). These dimensions seems to fit with the ethnographical examples. Another option would be that the rear wall and the rear side of the base plane were no aligned and that there was some space on the rear side of the house. In this case, the dimension of the front area would be reduced in size (Fig.123).

Regarding the ridge beam, its length should be at least equal to the distance between the two long forks, but it is also possible that it was longer. Unfortunately, since there are no reliable evidences and the possible "combinations" are almost infinite, at the moment we can only postulate that these dimensions are close to the real ones.

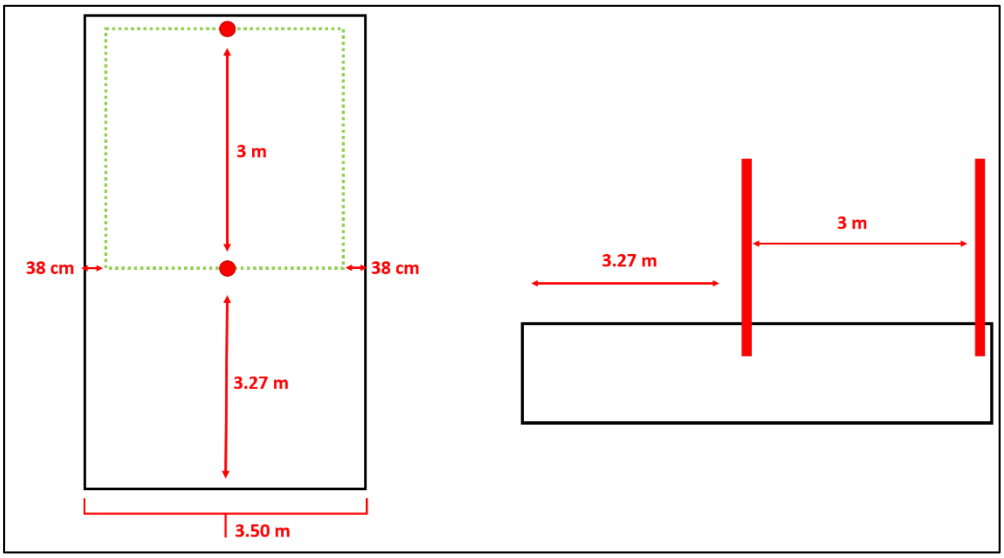


Fig.122: Dimensions of the house inner and outer spaces if the rear wall and the rear side of the platform were aligned (image by the author).

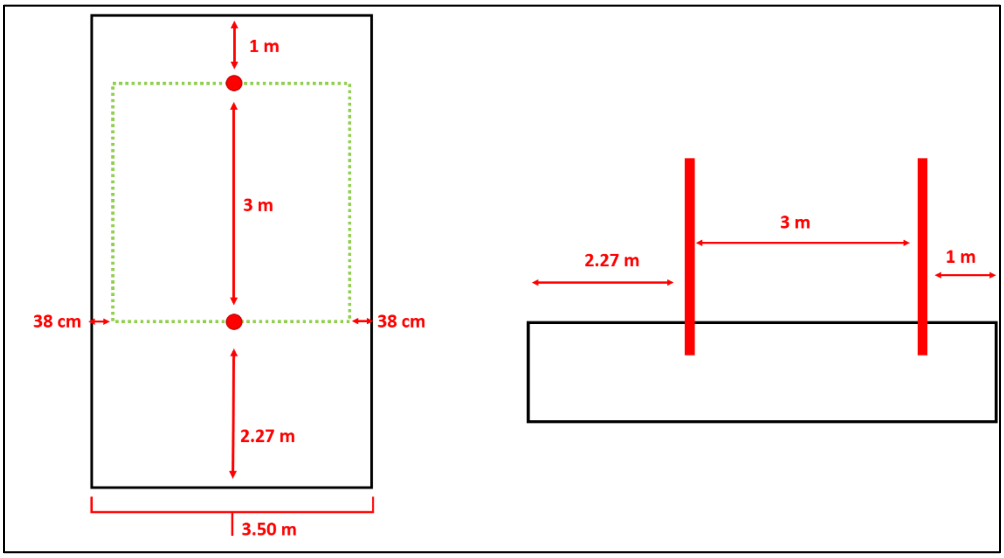


Fig.123: Dimensions of the house inner and outer spaces if the rear wall and the rear side of the platform were not aligned (image by the author).

As regards the high of the interior space of the house, we have the same problems saw for the interior width. We know that, so far, 9 complete long forks has been identified and their length ranges between 2 and 3.12 m and we know that the longest forks was probably plunged into the soil for 52 cm. This means that, if our hypothesis is correct and the long forks were indeed used as support for the ridge beam, the interior of the house varies from house to house. In our reconstruction (Fig.124), to postulate the inner space of the house, we decided to use longest fork (3.12 m) as point of reference. As said above, its proximal extremity was probably plunged into the soil for at least 52 cm, meaning that the remaining external part was 2.60 m long. Then we have to take into account that the high of the inner space of the house is defined by the space that goes from the top end of the base plane to the ridge beam (that indicates the top end of the house). This means that, since the ridge beam rests on the distal extremity of the long forks, in order to measure the house inner high we have to measure the length of the forks from the intersection point with the base plane to their V-shape extremity. Therefore, knowing that the base plane was 30 cm high we subtract this value from the total length of the long forks. The resulting dimension, 2.30 m indicates both the length of the long forks from the intersection point with the base plane to their V-shape extremity, both the high of the house inner space (Fig.124).

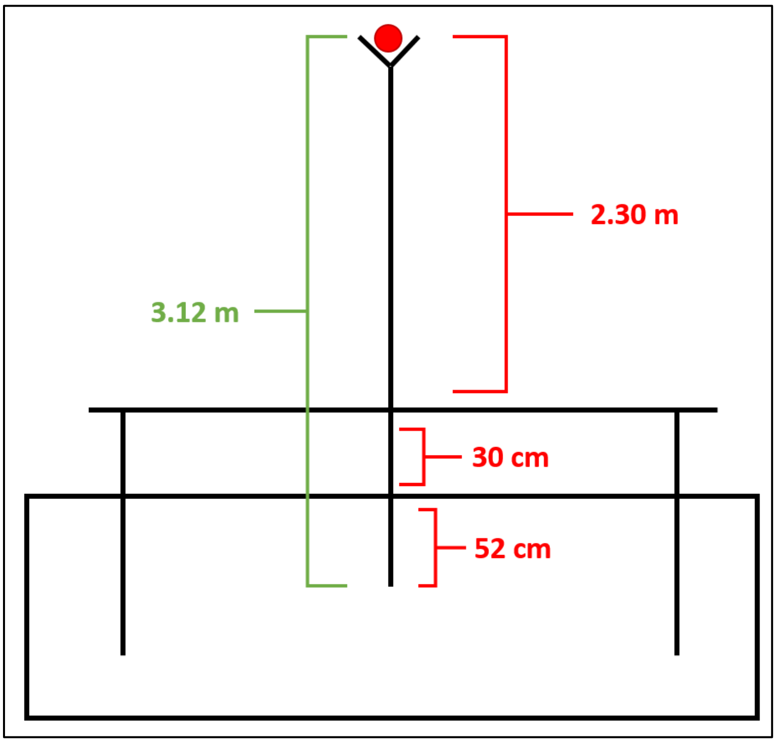


Fig.124: Hypothesis for the house height (image by the author).

4.2.2. Overhead Plane Linear Elements – Tilted Elements

Secondary linear element of the base plane were the tilted elements, a group including 150 piles artificially tilted (Fig.125). These elements have diameters that range between the 14 and the 191 mm. The majority of them has a diameter between 21 and 70 mm with a peak around the 31 – 40 mm (34 elements). The study of the orientation of these posts revealed that the majority of them is tilted towards West (32 elements) (López 2015). The average angle of these elements is about 60º-55º.

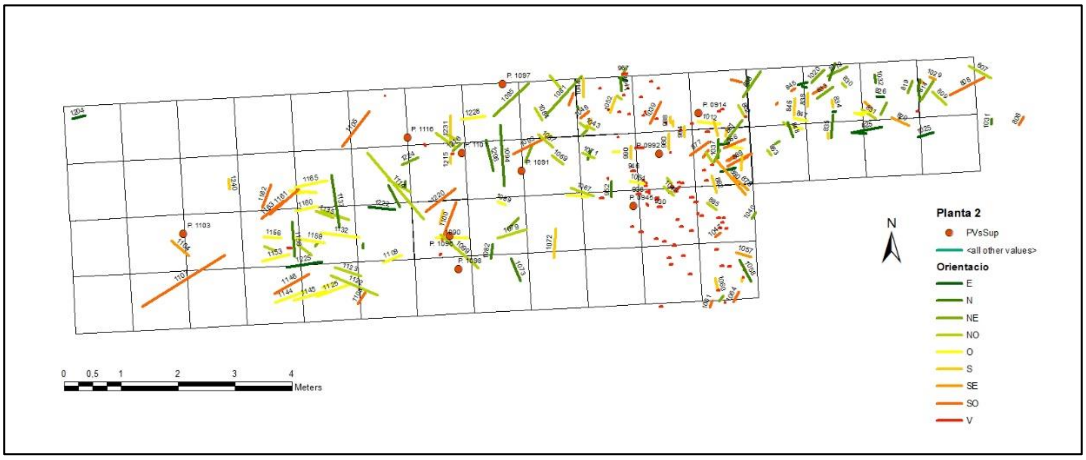


Fig.125: The tilted elements in sector D and their orientation (I. Bogdanovic).

The spatial analysis seems to indicate that these elements were in connection with the vertical piles and the short forks. Our hypothesis is that tilted elements, or at least some of them, were part of the lateral wall/roof giving the house the peculiar form known as "A-shape".

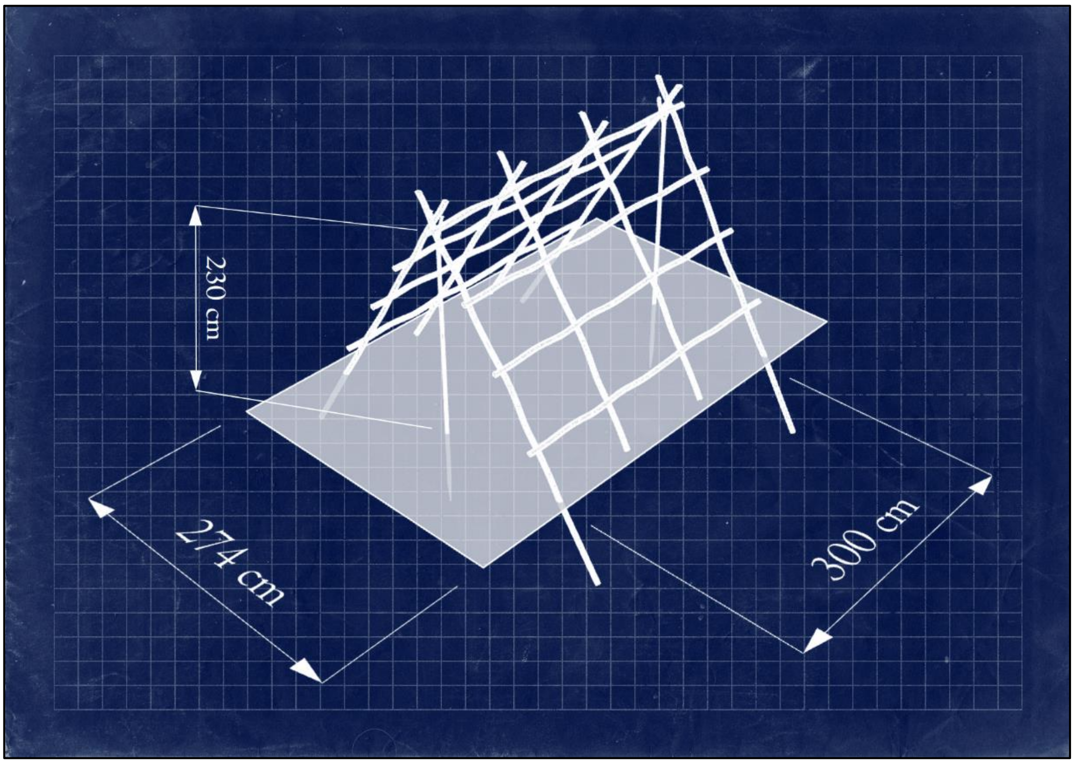


Fig.126: Reconstruction of the overhead frame and its dimensions (blueprint by the author).

We reached such a conclusion by analysing the data in our possession and by comparing them with archaeological data coming from other Neolithic pile dwelling settlements and from ethnographical comparison.

As I said, in our reconstruction, with the exception of the frontal and rear wall, there are no vertical walls: the tilted elements wold acted both as roof pitches and lateral walls, resting against the ridge beam (Fig.126).

The first element that oriented us in this direction was that, while in the other Neolithic pile dwellings analysed there are traces, usually clear, of vertical walls (like posts or postholes in pairs or threes) at La Draga there are no such evidences. As said in section 4.1.2. there are only two probable alignments of short forks (P1162, 1116, 1160, 1132; P1132, 1115, 1216, and 1095) but is a long shot (Fig.127).

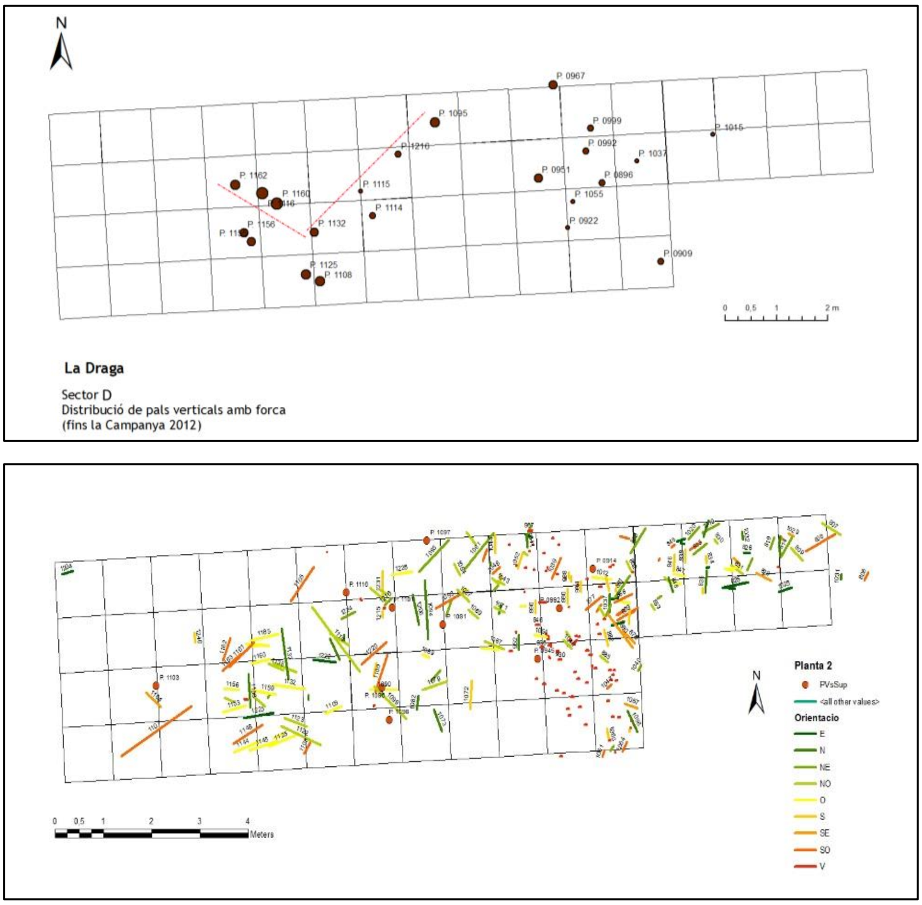


Fig.127. Top: Possible alignments in sector D (photo by I. Bogdanovic). **Bottom:** the tilted elements in sector D (I. Bogdanovic).

On the contrary, rows of posts artificially tilted has been found (Fig.127) and, accordingly with the archaeological team, they seems to be in connection with the short forks and the other vertical elements.

The second element was that some of these tilted piles have a slope degree that seems to be compatible with our reconstruction, in particular those elements with a slope degree between 60-55º. In fact, as we said, we postulated that these tilted elements rested on the ridge beam. Since the ridge beam is 2.60 high from the floor the tilted elements with an incline between 60-55º would rest on it (Fig.128). Obviously, this values works if we use the dimension postulated so far (2.30 m for the interior high and 2-74 m for the interior width).

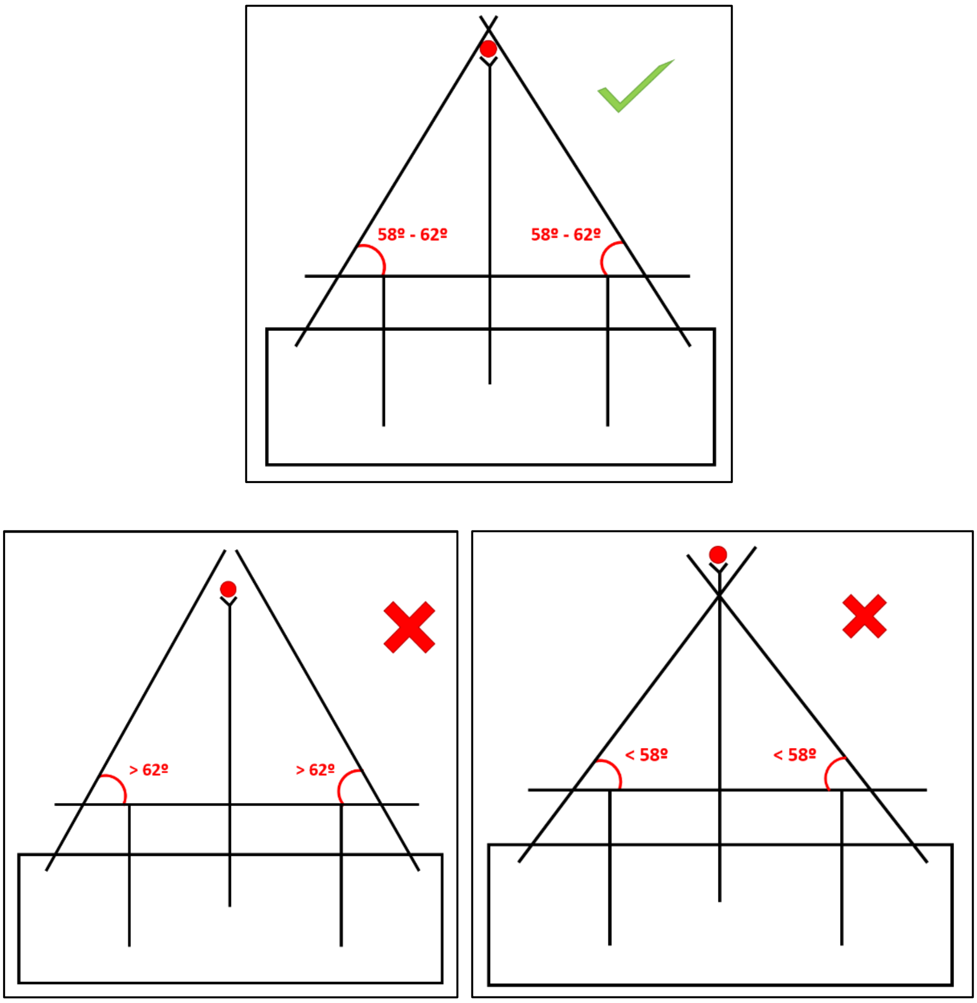


Fig.128: Reconstructing the wall pitches. **Top**: position of the roof pitches with an inclination of 60-55º. **Bottom**: position of the roof pitches with an inclination greater than 60º (**left**) and lesser than 55º (**right**) (images y the author).

Changing the other dimensions would change also the incline value. In our specific case however, the angle cannot be greater than 60º degree otherwise, the incline exceed the high of the ridge beam, and the tilted elements would not touch it (Fig.128). On the other hand, it could not be lesser than 55º or the tilted pile would "miss" the ridge beam. Moreover, this process allow us to determine the roof angle (of our reconstruction), which appears to be c. 59.22º.

Regarding the number of tilted piles used in order to build the roof pitches/lateral walls, we have no evidences. Without dendrochronology is it impossible to say which piles were contemporary. Moreover, even if contemporary, some of the piles could be add shortly after the first ones, for example to reinforce the structure.

However, we can advance some hypothesis by observing the other archaeological pile dwelling sites and by analogy with modern pile dwellings. Archaeologically wise, the spacing between the piles composing wall vary from site to site (e.g. Clairvaux 1-2 m; Maharski prekop 1.7-2.4 m). However, we have evidences only of those piles found plunged into the soil: there is no way to know if other piles, maybe resting just on the platform, were used. Ethnography both illustrates this problem and give us more data about the wall components. Examples as Nokoué, Nocte, Zancudos, Badjao and Nampan show that in addition to the piles plunged into the soil also piles resting just on the base plane are used (Fig.129). Moreover, even if each case is different it seems that the vertical elements of the wall are more or less regularly spaced, seemingly always around 1 m (we do not have direct information but observing the photos our estimation seems correct).

Fig.129: A Hetin-Sota house on Lake Nokoué (Benin) (Pétrequin 1988).

Since both archaeological and ethnographical examples seem to indicate that usually, the distance between the vertical elements forming the walls is c. 1 m we decide to use the same measure in our reconstruction. This gives us 8 tilted elements in total (4 for side). Since, as said above, it can be observe quite often there are elements not plunged into the soil but just resting on the base plane we also decided to put 4 of them resting of the floor.

The tilted elements inserted into the terrain would act as “principal rafters”. A principal rafter in a timber-framed house, one of several such rafters that extend from the ridge of the roof down to the wall plate; somewhat heavier than a common rafter; often located at a corner post, story post, or chimney post and framed into a tie beam. Principal rafters, together with the principal purlins, form a roof framing system having considerable stability.

The elements resting on the floor would be the so called “common” rafters: a series of inclined structural members from the ridge of the roof down to the eaves, providing support for the covering of a roof.

As we said, there is no way to know the exact number of elements used as rafters.

As for the overall length of the tilted elements at the moment we have no way to measure it since all of them lost their distal part due to rot action or other destructive actions. We can say though, that the tilted elements should at least “touch” the ridge beam and be plunged into the soil (even if we do no not how deep), in the case of the principal rafters, and the floor, in the case of the other elements (Fig.130). Our hypothesis is that the principal rafters were at leas c. 3 m long (postulating that they were inserted into the terrain for 20 cm). The others “common” rafters would be at least 2.30 m long.

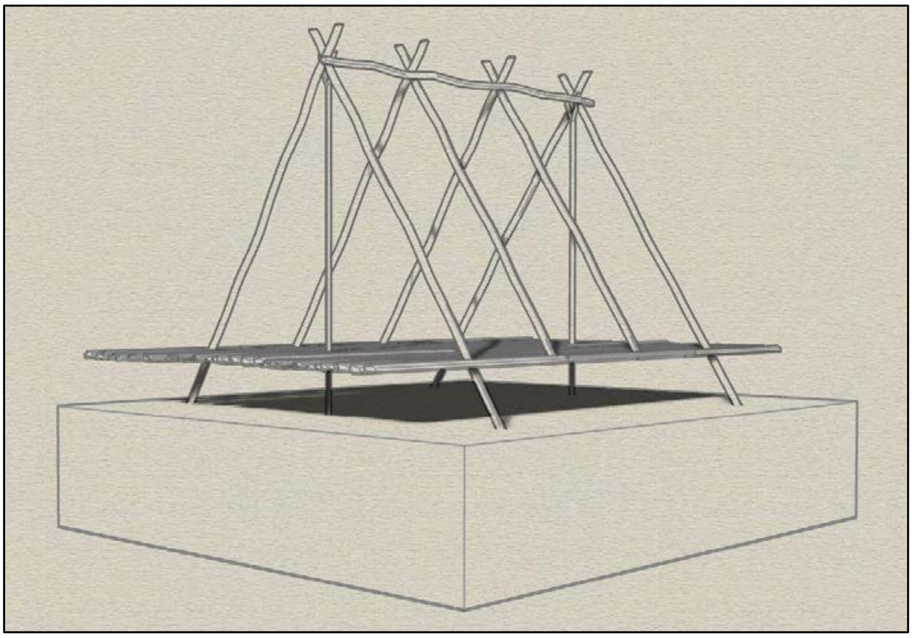


Fig.130: Reconstruction of rafters location (image by the author).

Similar assemblage can be observed in the “Shaman’s hut” at Lake of Ledro (Italy), and the Sumbawa houses (Fig.131).

Fig.131. Top: the "Shaman Hut" on Lake Ledro (Italy) (www.stock.adobe.com). **Bottom**: Sumbawa house (Indonesia) (http://trip-suggest.com).

Finally, we used the data related to the rafters to postulate the interior space width or the "span" the distance between the roof pitches. We determine that, in order to do that we have to calculate the point of intersection between the overhead plane and the base plane. To do so we took the overhead plane incline (60-55º) and the high of the base plane (1.40 m), overlaying the data.

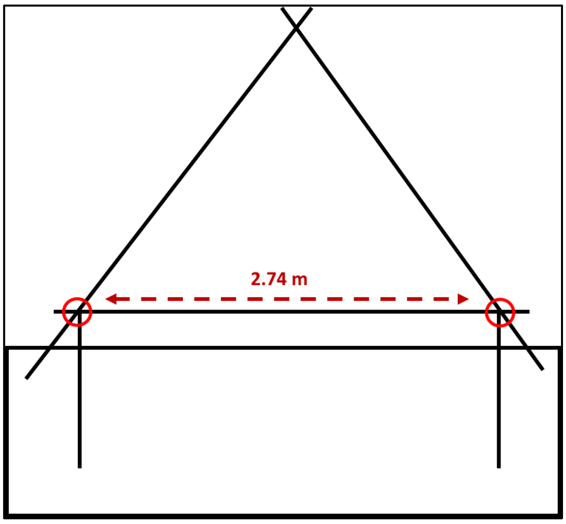


Fig.132: The house interior width (image by the author).

Once we found the intersection points we measure the distance between the two roof pitches at this point. The result indicates the interior width of the house: 2.74 m (Fig.132).

4.2.3. Overhead Plane Framing

There are two system of framing: heavy-framing, where the vertical supports are few and heavy, and the light-framing where the supports are more numerous and smaller. The overhead plane framing at La Draga probably belonged to this second category.

Observing both modern and Neolithic pile dwellings overhead planes is it possible to see how the roof pitches consist, almost always, of a frame made of crisscrossed elements meant to house the roof sheathing in order to protect the pile dwelling interior. Archaeological wise rarely elements of the overhead frame are found and we have to rely mostly on the reconstructions. Some examples are Clairvaux, Torwiesen II, Hornstaad-Hörnle IA, Maharski prekop, Dispilio, Robenhausen (Fig.133).

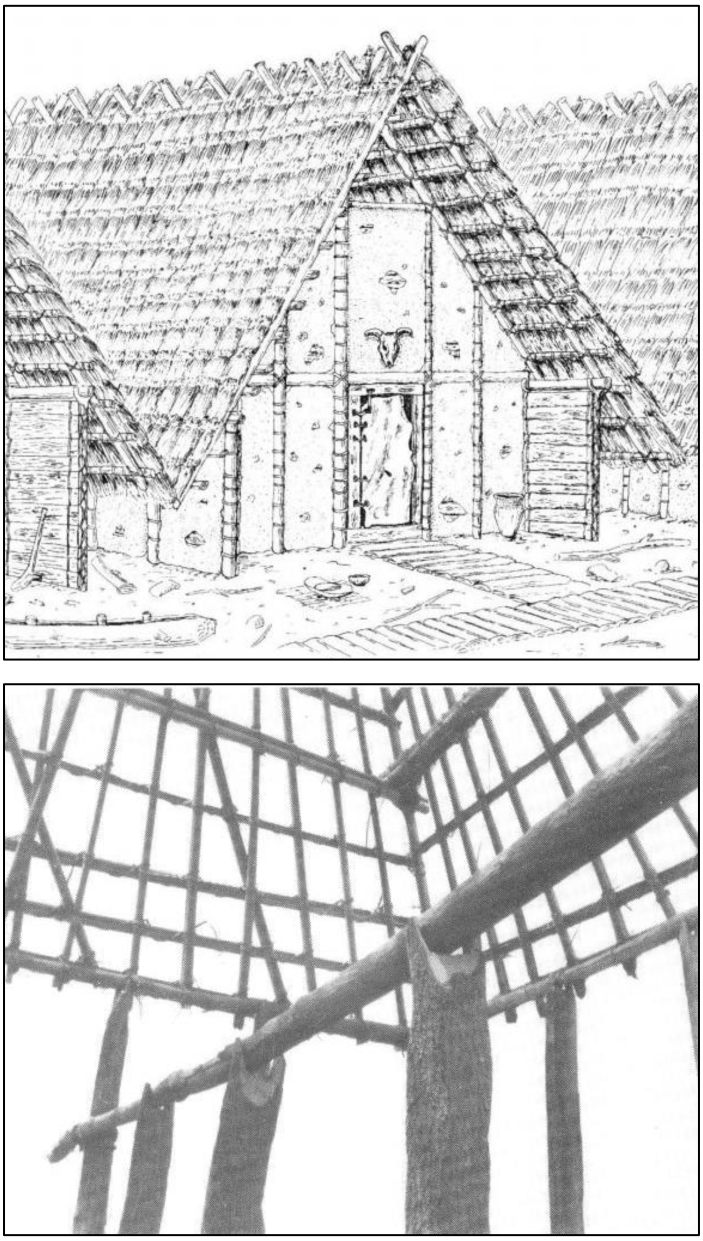


Fig.133. Top: Robenhausen house reconstruction (Altorfer, 1999). **Bottom**: Hetin-Sota house on Lake Nokoué (Benin), particular of the roof framing (Pétrequin 1988).

Ethnography show that this framing system is widely diffuse when it comes down to build the overhead plane. The Badjao houses, the Chin houses, the Sumbawa houses, the Bajau houses, the Akha houses, the Nipa houses, the Port Quepos houses are just some examples (Fig.133). In all these cases, the roof pitches are made of a framing made of perpendicular crisscrossed elements. The spacing among the frame elements vary from site to site probably based on the material used to build the sheathing.

At La Draga, we have no direct evidences of such a structure, however archaeological and ethnographical analogies seem to indicate that our hypothesis about the presence of a roof framing could be correct. Moreover, as described in section N we postulated that that the roof pitches of the house were made of tilted elements and, even if it possible that the roof pitches were made only of lots of tilted elements leant against the ridge beam, the use of a framing system seems more likely. Of the vertical (in this case tilted) elements acting as rafters, we already spoke in section 4.2.2.

As regard the horizontal elements, 494 wooden elements has been recovered so far in sector D. The diameter of these elements range between 7 mm and 210 mm with the majority of them between the 21-30 mm and the 111-120 mm (Fig.134).

Diàmetre (mm)	Nº	%
01-10	2	0,40
11-20	6	1,21
21-30	39	7,89
31-40	77	15,59
41-50	78	15,79
51-60	86	17,41
61-70	49	9,92
71-80	37	7,49
81-90	30	6,07
91-100	26	5,26
101-110	17	3,44
111-120	16	3,24
121-130	8	1,62
131-140	9	1,82
141-150	5	1,01
151-160	4	0,81
161-170	3	0,61
171-180		0,00
181-190	1	0,20
191-200		0,00
201-210	1	0,20
Total	494	

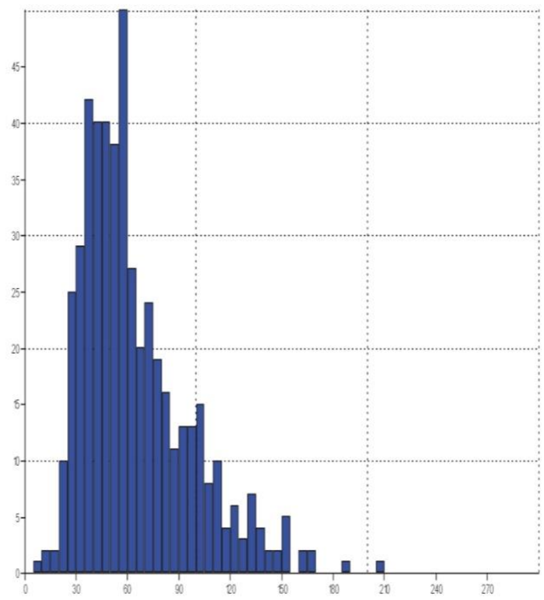


Fig.134: Diameters of the horizontal elements from sector D and their graphic representation (by groups of 5 mm) (López 2015).

Among these, the biggest group is the one represented by the elements with a diameter between 51-60 mm (86 elements).

In some cases (485 on 494) it has been possible to measure the length of the artefacts, although in few cases corresponds to the total length due to the fragmentation and preservation of remains, the majority of which range among

40-50 cm but with elements reaching 5 m.

Llargada (cm)	Nº	%
01-20	13	2,68
21-40	96	19,79
41-60	94	19,38
61-80	83	17,11
81-100	45	9,28
101-120	40	8,25
121-140	32	6,60
141-160	27	5,57
161-180	13	2,68
181-200	11	2,27
201-220	12	2,47
221-240	5	1,03
241-260	3	0,62
261-280	4	0,82
281-300	2	0,41
301-320		0,00
321-340	2	0,41
341-360	2	0,41
361-380		0,00
381-400		0,00
401-420		0,00
421-440	1	0,21
Total formes	485	
No determinat	9	1,82
Total	494	

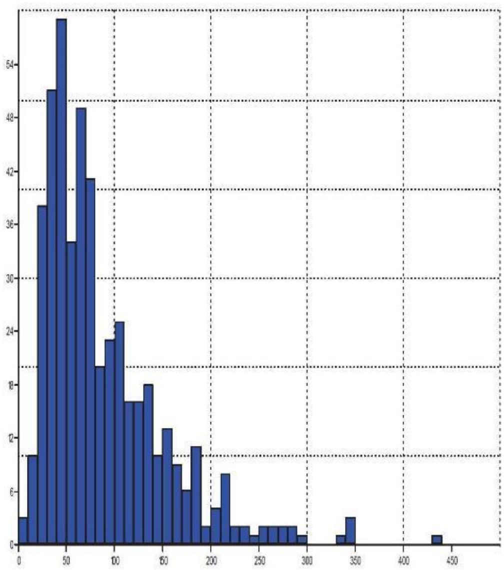


Fig.135: Length of the horizontal elements from sector D and their graphic representation (by groups of 10 cm) (López 2015).

The horizontal elements have been also divided depending on their longitudinal shape identifying five categories: straight elements (211 elements); curved elements (60); planks (110); angles (24) and forks (18) (López 2015) (Fig.136).

	Nº	%
Recte	211	49,88
Corba	60	14,18
Tauló	110	26,00
Angle	24	5,67
Forca	18	4,26
Total formes	**423**	
Incomplert	49	9,92
Informe	22	4,45
Total	**494**	

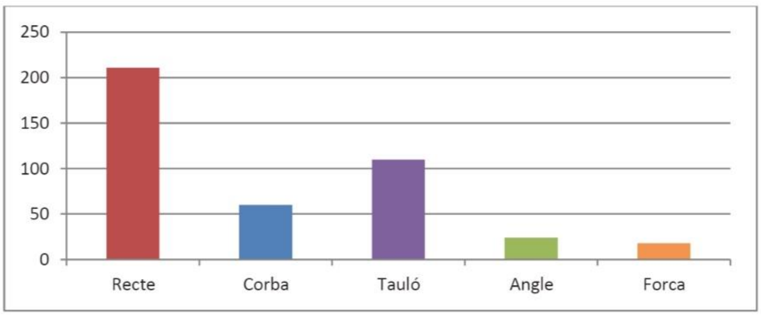


Figura 209 - Resultats de l'anàlisi de formes de les fustes horitzontals i la seva representació gràfica.

Fig.136: The forms of the horizontal elements (López 2015).

Excluding those elements probably used for other duties (forks, planks, angles), remain 271 suitable elements to build the roof framing. However, some of these horizontal elements lost their distal extremity preventing us from determining their overall form. Moreover, the lack of dendrochronology prevents us from determining how many of these elements were used at the same time but the stratigraphic analysis seems to indicate that they belong at a same period of time (Chinchilla *et al.* 2013). Despite these problems seems reasonable hypothesizing that some of these elements were used as elements for the roof pitches framing. These elements would act as purlins: elements that lays horizontally on the rafters and usually runs parallel to the ridge of the roof. Together with the rafters they form the roof framing.

It is impossible to say how many of these elements were indeed used to build the framing system and their spacing. In our model, we used 8 elements (4 for pitches) but it is a number based only to create a framing with a regular spacing among its components. The resulting framing would be of the light-framing type since there seems to be no heavy supports connected with it (Fig.137).

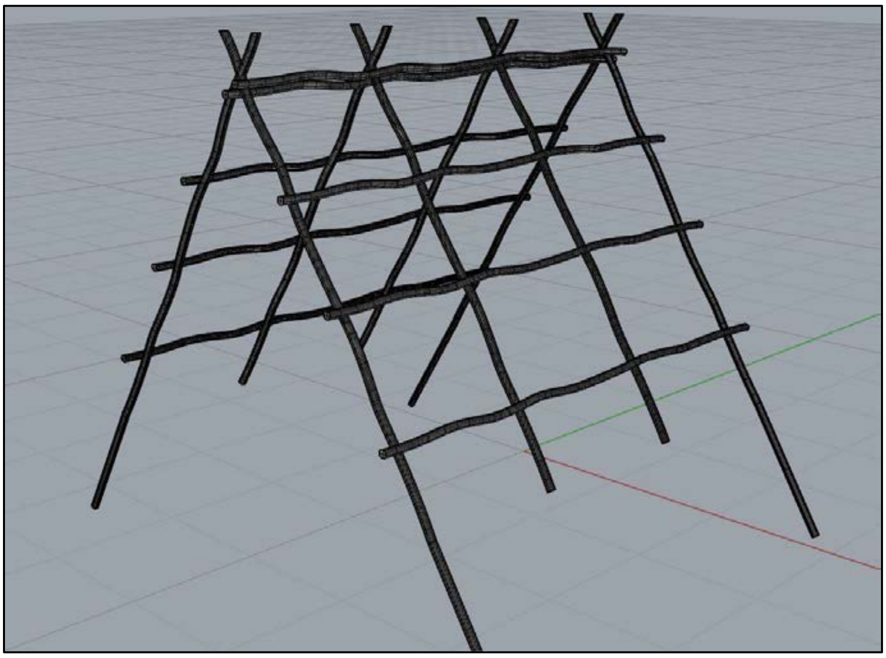


Fig.137: 3D model built in Rhino 5 ad representing the overhead framing meant to hold the roof/walls sheathing (model by the author).

4.2.4. Overhead Plan Openings – Windows

At La Draga there is no evidence suggesting the presence of any apertures on the overhead plane. Moreover, neither the archaeological examples nor the ethnographical ones show the presence of windows on the overhead plane (Nipa house, Badjao house etc.) (Fig.138). Ethnographical analogy has shown that in many cases (e.g. the Paniduria Nocte; Afari Trine house, Sumbawa houses) simple houses with walls made of vegetal elements have no needs of openings since the smoke simply goes out through the wall sheathing (Levy *et al.* 2004). The absence of opening also diminishes the loss of heat. Moreover, in case they needed an opening, the composition of the walls would allow them to obtain a hole in it.

Fig.138: An example of Badjao pile dwelling roof (Philippines) (www.iom.int).

4.2.5. Overhead Plane Sheathing

The task of the sheathing, both of the overhead plane and the vertical plane, is to define and enclose the house interior, granting a “safe area” protected from the weathering effects and other possible threats. The material and technique used to build the sheathing vary widely however, usually, in the most “primitive” settlements the local materials are used.

Archaeologically, finding traces of the original overhead (roof) sheathing is very difficult especially in pile dwelling settlements. The few evidences we have seems to indicate that, usually, the roof covering was made of local vegetal materials like straw, reeds or unwind bark vegetal elements from the nearby area were used as a at Clairvaux, Torwiesen II, Hornstaad-Hörnle IA (Fig.139) and Dispilio (Pétrequin 1988; Pawlik 1993; Mazurkevich 2013).

Fig.139: Hornstaad-Hörnle, house reconstruction (www.misteroriginal.com).

Ethnography seems to support this theory since all the pile dwellings analysed used natural vegetal elements as roof sheathing. The Badjao houses (Sulu Archipelago, Philippines), have their roof made of bamboo or/and palm's branches while in the Samal houses, on the same Archipelago, the roofs covering is made of wood. Other examples are, the Nipa houses (Fig.140), the Sumbawa's houses, the Hetin-Sota houses on Lake Nokoué, the Bajau's houses etc. The sheathing components are usually tied together using different techniques and then tied to the roof framing.

At La Draga no direct traces of the material used as overhead plane sheathing has been found. However, a huge quantity of oak's branches, some of them seemingly intertwined, has been found during the excavation. These elements have been interpreted as part of the sheathing, probably completed by the use of other local materials as fresh/dry aquatic/terrestrial plants and/or leafs.

Fig.140: A Nipa house roof made using palm leaves sewed togheter (myphilippinelife.com).

4.2.6. Overhead Plane Dimensions

The only direct data that we have about the overhead plane dimension are the dimensions of the long forks the longest of which measure 3.12 m. This fork was inserted into the soil for 52 cm while the remaining 2.60 m were jutting out from it. In order to hypothesize the other dimensions of the overhead plan we take this fork ad point of reference and the dimension coming from the other planes. The dimensions we needed include:

- The high of the house inner space
- The length of the house inner space
- The width of the house inner space
- The probable length of the tilted elements (rafters)

<u>The high of the house inner space</u>

The high of the inner space of the house is defined by the space that goes from the top end of the base plane to the ridge beam (that indicates the top end of the house). This means that, since the ridge beam rests on the distal extremity of the long forks, in order to measure the house inner high we have to measure the length of the forks from the intersection point with the base plane to their V-shape extremity. As said above, to postulate the high of the house inner space we decided to use longest fork found (3.12 m) as point of reference. Its proximal extremity was probably plunged into the soil for at least 52 cm, meaning that the remaining external part was 2.60 m long. Knowing that the base plane was 30 cm high we subtract this value from the previous value (2.60 m). The resulting dimension, 2.30 m, indicates both the length of the long forks from the intersection point with the base plane to their V-shape extremity, both the high of the house inner space. It also indicates the high of the ridge beam.

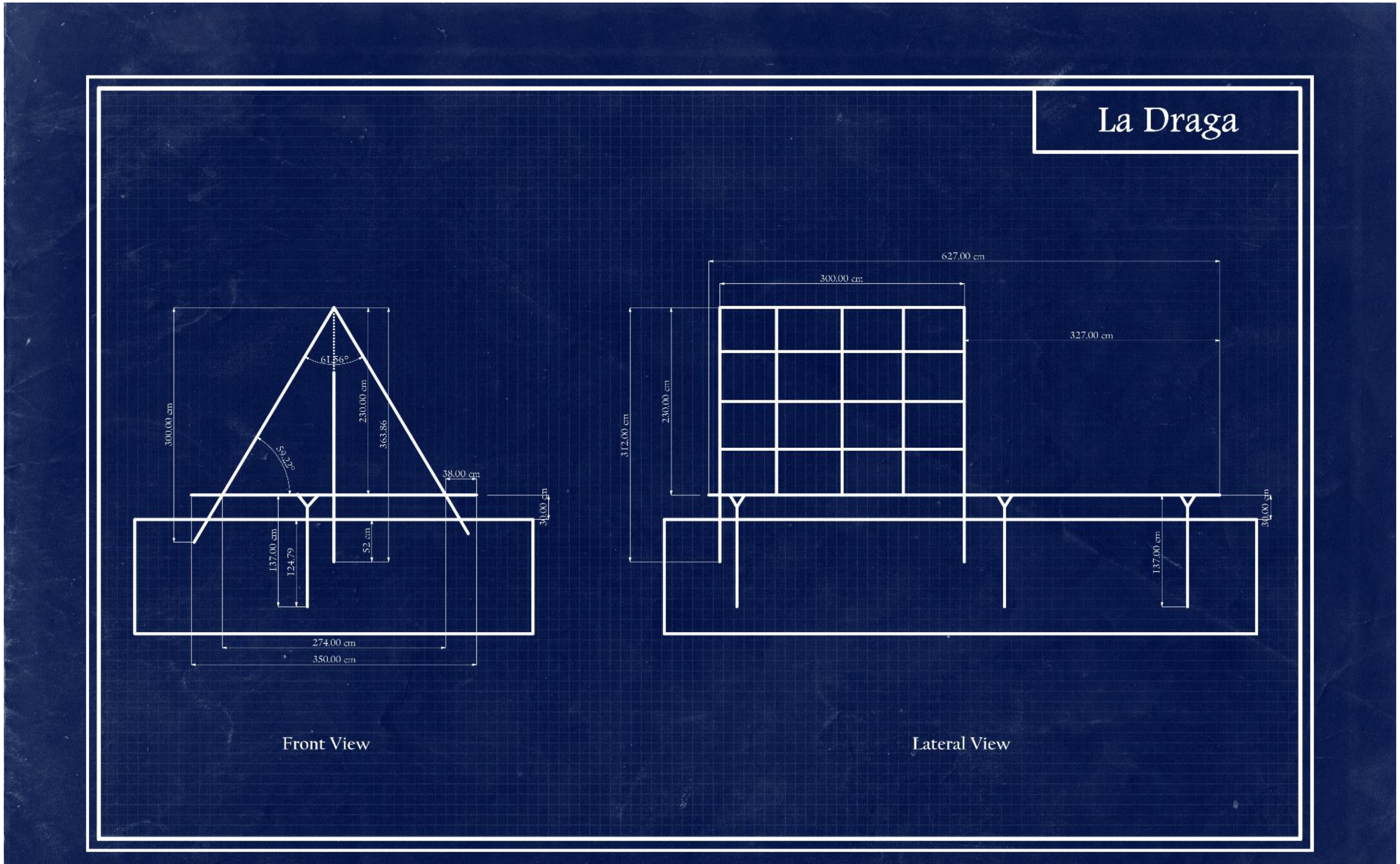
The length of the house inner space

The length of the inner space of the house is defined by the space that goes from the front side to the back side. At La Draga, e used the long forks acting as main post as point of references. As said in section N, we postulated that some space was probably saved to undertake different activities on the base plane, outside the house meaning that the house width should be lesser than the base plane overall width, which measures 6.27 m. Second, even if we do not know the real composition of the "families" living at La Draga, we can imagine that a house should at least shelter two peoples meaning that the interior space should be at least two-three meters of length. Considering all these data, we postulated that the distance between the two long forks acting as main post could be of 3.00 m meaning that the front area for the activities should be 3.27 m long.
Regarding the ridge beam, its length should be at least equal to the distance between the two long forks, but it is also possible that it was longer.

The width of the house inner space

The width of the inner space of the house is defined by the distance between the lateral walls. At La Draga, since the lateral walls and the roof pitches coincide, we calculated the width of the inner space measuring the distance between the roof pitches. As described in section N, the roof pitches were made of several tilted elements acting as rafters and main rafters. The tilted elements compatible with the inner high postulated had a slope between 60-55º. We used these data to calculate the “span”, the distance between the roof pitches. We determine that, in order to do that we had to calculate the point of intersection between the overhead plane and the base plane. To do so we took the overhead plane incline (60-55º) and the high of the base plane (1.40 m), overlaying the data.

Once we found the intersection points we measure the distance between the two roof pitches at this point. The result indicates the interior width of the house: 2.74 m.



Blueprint showing the frontal and lateral view of La Draga pile dwelling and its probable dimensions (blueprint by the author).

4.2.7. Overhead Plane Connections

Although both rolls of lianas and ropes made of thin twisted fibres have been recovered at La Draga (Piqué *et al.* 2016) (Fig.141), there are no evidences that they were used as connections to tie together the different elements composing the overhead plane nor we have evidences about how its different elements were tied together and to the other house planes. However archaeological and ethnographical comparison seems to indicates that lianas and ropes were indeed used to connect the various parts of the vertical plane

Fig.141. Top: A piece of rope from La Draga. **Bottom:** A lianas bundle found at La Draga (bothe the images from Bosch *et al.* 2006).

Evidences of lianas and/or ropes have been collected from several archaeological pile dwelling sites (e.g. Serteya II, Clairvaux, Sutz-Lattrigen, Riedstation, Hornstaad-Hörnle IA). However, these evidences are often fragmentary and give us little information. Ethnographical analogy, on the other hand, display both the use of natural fibres (in different forms) as connection and can give us an indication about how these connections were used in the past. All the modern pile dwellings taken into account (among the others: Nipa houses; Sri Ma houses; etc.) shown the same solution: the crisscrossed elements of the wall framing were tied together with different types of natural fibres (replaced, in some cases, by strings of modern material like plastic ropes) (Fig.142). The framing was attached to the rest of the house in the same way and it acted as base for the sheathing.

Fig.142: Roof detail of a Sri Ma house base plane (Auroville, India) showing the overhead framing. The elements are tied together using ropes made of natural fibres (www.auroville.org).

4.3. VERTICAL PLANE OF LA DRAGA HOUSE

As described in chapter 3 vertical plane includes all those vertical elements that serve as structural supports for the overhead/roof plane. There are vertical linear elements, like the columns, and vertical planes, usually identified with the walls. Exterior wall planes isolate a portion of space to create a controlled interior environment. Their construction provides both privacy and protection from the climatic elements for the interior spaces of a building, while openings within or between their boundaries re-establish a connection with the exterior environment. As exterior walls meld interior space, they simultaneously shape exterior space and describe the form, massing, and image of a building in space. Interior wall planes govern the size and shape of the internal spaces or rooms within a building. A vertical plan has two opposed surfaces or faces, which establish two distinct spatial fields. These two faces can differ in form, colour or texture to articulate different spatial conditions. The height of the vertical plane relative to our body height and eye level is the critical factor that effects the ability of the plane to describe, visually, spaces giving, for examples, different sense of enclosure. As a design element, a wall plane can merge with the floor or ceiling plane, or be articulated as an element isolated from adjacent planes. It can be treated as a passive or receding backdrop for other elements in the space, or it can assert itself as a visually active element within a room by virtue of its form, colour, texture, or material. A compelling way to use the vertical wall plane is as a supporting element in the bearing- wall structural system. While walls provide privacy for interior spaces and serve as barriers that limit our movement, doorways and windows re-establish continuity with neighbouring spaces and allow the passage of light, heat, and sound (Pramar 1973; Ching 2014).

As described in the previous chapter, the archaeological evidences found so far at La Draga, seems to indicate that the roof pitches of the house acted both as roof and lateral/main walls. This particular arrangement implies that the vertical plane was most likely composed only of two vertical walls, meant to close the house on the front and on the back side.

The characteristics of the walls and the sheathing are proposed according to:

- The spatial localizations and main features recorded on the architectonical elements from la Draga.
- The data obtained from the reconstruction of the other house planes.

- Data obtained from the analogy with both ancient and modern pile dwelling sites (chapter 2).

According with our theory, the vertical plane was composed of two vertical walls made of crisscrossed wooden elements (like piles and branches) arranged in two frames (one on the front, one on the back) (Fig.143). The vertical elements of the frames rested on the base plane while the horizontal elements were probably just tied to them. The resulting frames leaned against the main rafters of the overhead plan, probably tied using lianas and/or ropes. The presence at La Draga of elements composed of oak branches intertwined seems to suggest that the wall sheathing was made of these elements.

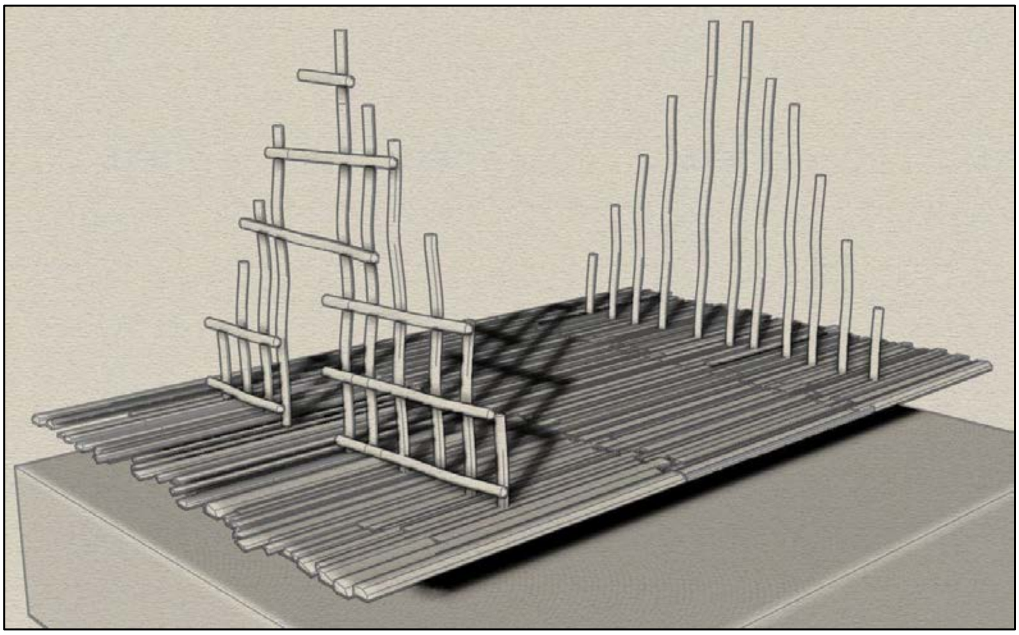


Fig.143: Reconstruction of the vertical walls (image by the author).

Using our general descriptive model, we described the vertical plane as made of natural elements, probably both worked and not worked, and as monofunctional since we postulated that it acted just as walls.

4.3.1. Vertical Plane Linear Elements

As described in chapter 2.7, are considered linear elements those building components having the necessary material strength to perform structural function. They can provide support for an overhead plane, form a three-dimensional structural frame for architectural space and express movement across space. Row of linear elements could be used to support the floor or roof plane above. How these linear elements affect the texture of a surface will depend on their visual weight, spacing, and direction (Pramar 1973; Ching 2014).

In our reconstruction, the vertical walls structures rely, to stand, on the overhead and base plane elements, meaning they performed no structural function. Their sole role was closing the house on the front and on the back, providing a protected area, and support the sheathing.

4.3.2. Vertical Plane Structure – The Framings

At La Draga, there is no direct evidences about the vertical plane structure and its elements. However, using the data at our disposal and through archaeological and ethnological analogy, we were able to formulate reliable hypothesis.

Regarding the archaeological data at La Draga, in sector D, 271 vertical elements thrusted into the soil has been recovered. Of these 271 elements 155 where rectilinear and 89 curved that is 244 piles that could have be used to build the vertical walls, while the remaining had clearly another use (e.g. forks) (Fig.145).

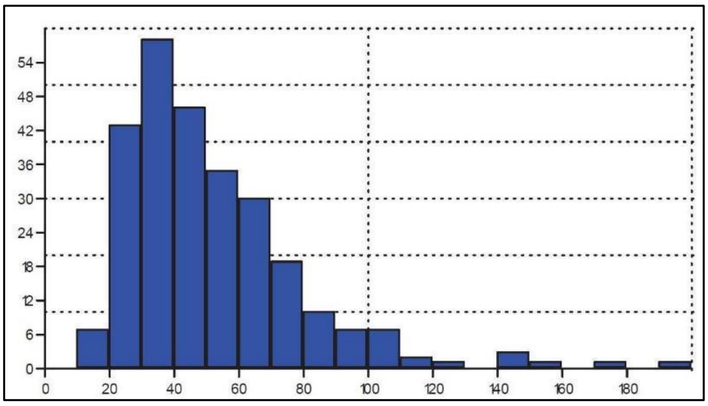


Fig.144: Graphic representation of the diameters of the vertical elements found in sector D (López 2015).

These piles had diameter that range between 2 and 8 cm with a peak between 2 and 6 cm (190 elements) (Fig.144).

DIÀMETRE (mms)	Nº	%
01-10	0	
11-20	8	2,95
21-30	47	17,34
31-40	59	21,77
41-50	46	16,97
51-60	38	14,02
61-70	25	9,23
71-80	19	7,01
81-90	6	2,21
91-100	7	2,58
101-110	7	2,58
111-120	3	1,11
121-130	0	
131-140	0	
141-150	3	1,11
151-160	1	0,37
161-170	0	
171-180	1	0,37
181-190	0	
191-200	1	0,37
TOTAL DETERMINAT	271	

	2010/2012	
	Nº	%
Recte	155	57,41
Corba	89	32,96
Angle	4	1,48
Forca	22	8,15
Total formes	**270**	
Informe	1	0,37
Total analitzat	**271**	

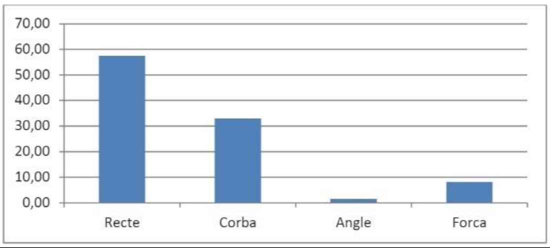
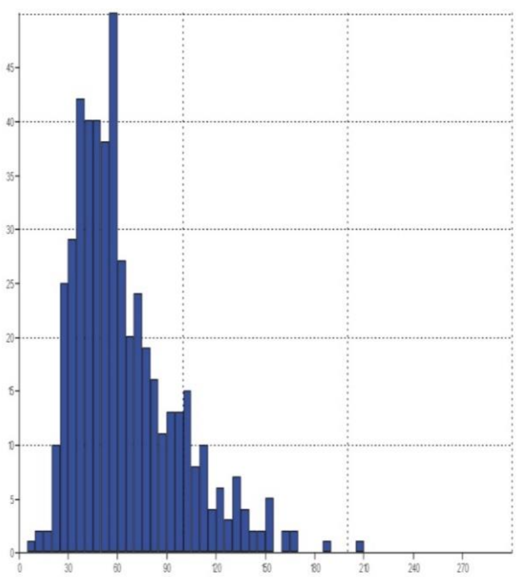


Fig.145. Top: Diameters of the vertical elements found in sector D (López 2015). **Bottom:** Vertical elements forms (López 2015).

However, most of these piles lost their distal parts (155) preventing us from determining their overall form (i.e. if they were, forks, piles etc.). Moreover, the lack of dendrochronology prevents us from determining how many of these elements were used at the same time (Chinchilla *et al.* 2013), for example to build the wall. As regards the horizontal elements, 494 wooden elements has been recovered so far in sector D. The diameter of these elements range between 7 mm and 210 mm with the majority of them between the 21-30 mm and the 111-120 mm (Fig.146). Among these, the biggest group is the one represented by the elements with a diameter between 51-60 mm (86 elements). In some cases (485 on 494) it has been possible to measure the length of the artefacts, although in few cases corresponds to the total length due to the fragmentation and preservation of remains, the majority of which range among 40-50 cm but with elements reaching 6 m (Fig.146).

Diàmetre (mm)	Nº	%
01-10	2	0,40
11-20	6	1,21
21-30	39	7,89
31-40	77	15,59
41-50	78	15,79
51-60	86	17,41
61-70	49	9,92
71-80	37	7,49
81-90	30	6,07
91-100	26	5,26
101-110	17	3,44
111-120	16	3,24
121-130	8	1,62
131-140	9	1,82
141-150	5	1,01
151-160	4	0,81
161-170	3	0,61
171-180		0,00
181-190	1	0,20
191-200		0,00
201-210	1	0,20
Total	494	



Llargada (cm)	Nº	%
01-20	13	2,68
21-40	96	19,79
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61-80	83	17,11
81-100	45	9,28
101-120	40	8,25
121-140	32	6,60
141-160	27	5,57
161-180	13	2,68
181-200	11	2,27
201-220	12	2,47
221-240	5	1,03
241-260	3	0,62
261-280	4	0,82
281-300	2	0,41
301-320		0,00
321-340	2	0,41
341-360	2	0,41
361-380		0,00
381-400		0,00
401-420		0,00
421-440	1	0,21
Total formes	485	
No determinat	9	1,82
Total	494	

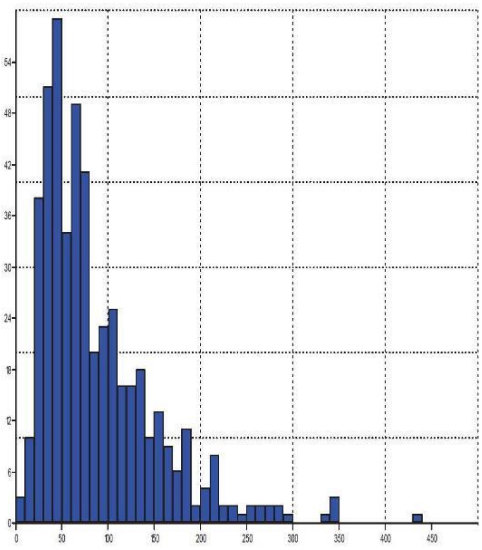


Fig.146. Top: Diameters of the horizontal elements from sector D and their graphic representation (by groups of 5 mm). **Bottom:** length of the horizontal elements from sector D and their graphic representation (by groups of 10 cm) (López 2015).

The horizontal elements have been also divided depending on their longitudinal shape identifying five categories: straight elements (211 elements); curved elements (60); planks (110); angles (24) and forks (18) (López 2015) (Fig.147).

	Nº	%
Recte	211	49,88
Corba	60	14,18
Tauló	110	26,00
Angle	24	5,67
Forca	18	4,26
Total formes	**423**	
Incomplert	49	9,92
Informe	22	4,45
Total	**494**	

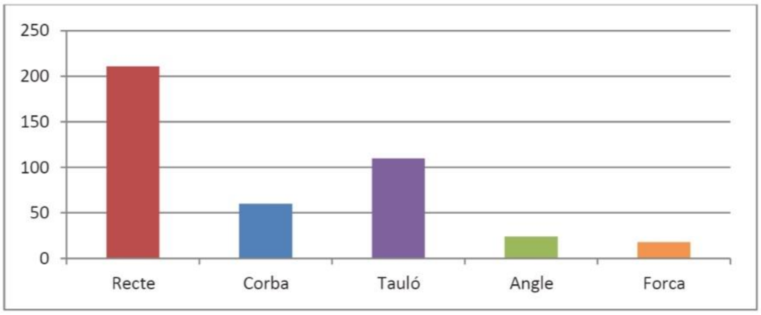


Figura 209 - Resultats de l'anàlisi de formes de les fustes horitzontals i la seva representació gràfica.

Fig.147: Horizontal elements forms (López 2015).

Excluding those elements probably used for other duties (forks, planks, angles), remain 271 suitable elements to build the walls. As for the vertical elements, also some of these horizontal elements lost their distal extremity preventing us from determining their overall form. In addition, the same problem with the dendrochronology remains, but the stratigraphic analysis seems to indicate that they belong at a same period of time (Chinchilla *et al.* 2013). Despite these problems seems reasonable hypothesizing that some of these elements were in fact part of the vertical plane.

Once we gathered these data, the following step has been to compare them with the reconstruction of the other planes, trying to understand the walls shapes. As shown in the previous section (4.2), according to our reconstruction, the houses at La Draga were "A-Shape" houses. This peculiar shape allow few architectonical solutions to close the structure on the front and back side. The simplest solution was building two vertical wall closing the triangular space between the roof pitches. We postulated that the constructors might have followed the same building techniques used for the other walls, namely the use of framing (this time vertical) as wall structure. As we said (chapter 4.2.3), there are two system of framing: heavy-framing, where the vertical supports are few and heavy, and the light-framing where the supports are more numerous and smaller. The vertical plane framing at La Draga probably belong to this second category. In our model, 20 (more or less) piles would be already enough to build the two framings. The resulting framings would be then tied to the roof rafters and possibly also to the frontal long fork.

This hypothesis about the use of framings seems quite probable since the use of framings as wall structure is a technique widely diffused in the ancient architecture, not only in the Neolithic and not only related to the pile dwellings (e.g. Clairvaux, Torwiesen II, Sutz-Lattrigen, Hornstaad Hörnle IA, Misling II), and it is still widely used in modern architecture (Encyclopaedia Britannica) (Fig.148,149).

Fig.148: Reconstructed pile dwellings of the site Torwiesen, Bad Buchau, Lake Federsee, Baden- Württemberg, Germany (http://www.federseemuseum.de/).

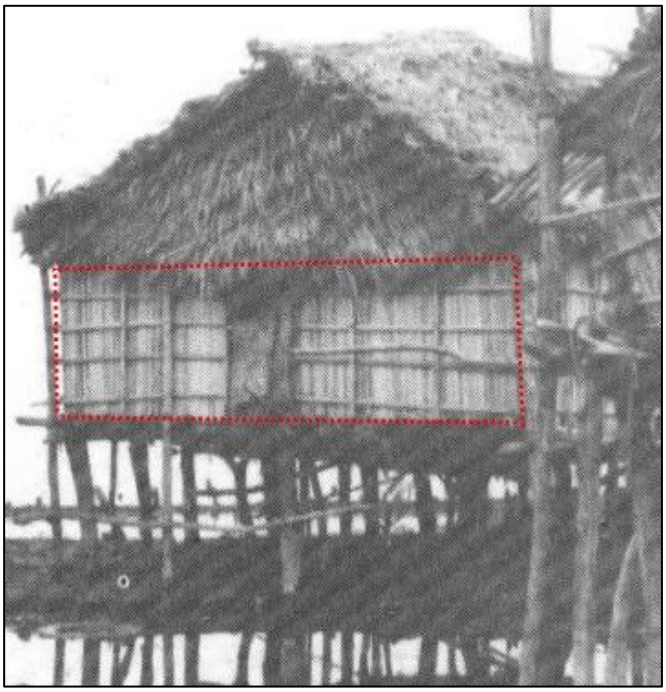


Fig.149: Wall framing in a Hetin-Sota house, (Benin) (Pétrequin 1988). In both cases, the framing system consists of criss-crossed elements tied together.

This kind of solution is, in fact, relatively easy to build and provide a reliable support.

Having established the presence of the necessary materials to build the walls and their overall shape, the following problem has been figure out if the walls vertical elements were thrusted into the soil (Fig.150), passing thought the base plane, or just rested on the base plane (Fig.151). In both cases, the frames were also probably tied to the overhead plane main rafters and main forks and to base plane framing.

Since most of the vertical wooden elements found in sector D were still thrusted into the soil, the first hypothesis (vertical elements thrusted into the soil) would seems very plausible. However, there are three main gaps. The first one is that many of these elements has lost their distal extremity, meaning that is impossible to know both their total length and their overall shape (i.e. if they were fork, piles etc.).

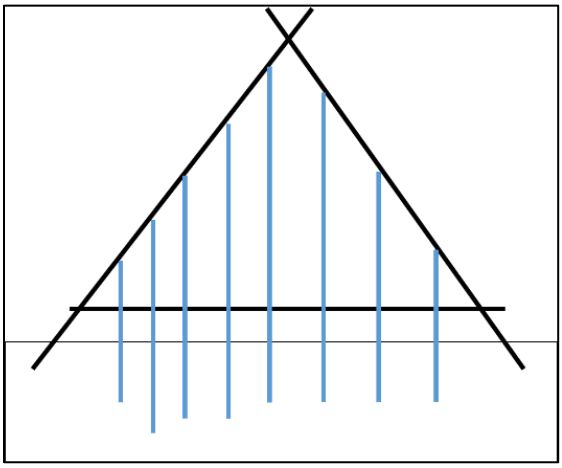


Fig.150: Vertical Plane reconstructive hypothesis nº 1 (image by the author).

The second problem is the lack of any piles alignment attributable to a vertical framing. The third gap is that we find no evidences, neither archaeological nor ethnographical, of this solution.

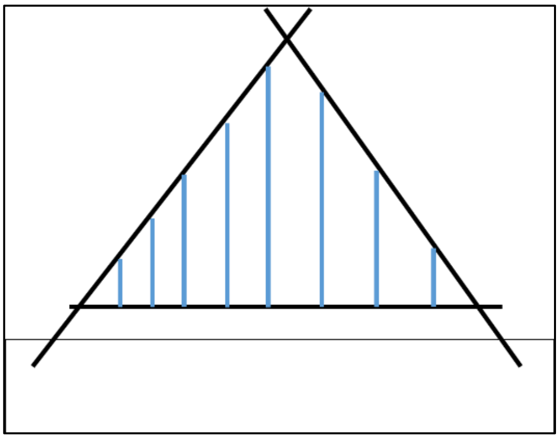


Fig.151: Vertical Plane reconstructive hypothesis nº 2 (image by the author).

The second hypothesis, instead, is that the vertical elements of the framing just stood on the base plane, specifically on the floor. Differently from the first hypothesis, this solution is documented in both archaeology and ethnography. Archaeologically wise, sites as Clairvaux, Torwiesen II, Sutz-Lattrigen, Hornstaad Hörnle IA (Fig.152), Misling II, Weyregg-Landungssteg, Schärfling, Maharski prekop, Serteya II, Dispilio, and many others shown the use of this very solution with vertical elements of the framing resting on the floor (base plan).

Fig.152: Hornstaad-Hörnle, house reconstruction (www.misteroriginal.com).

Ethnographically wise, this solution is widely documented. Among the examples we can mention: the Hetin-Sota pile dwellings on Lake Nokoué (Republic of Benin); the Badjao pile dwellings (Philippines); the Malaysian pile dwellings on Borneo Island; the Bajau Laut pile dwelling village (Malaysia); the Kri island (Indonesia) pile dwelling settlement; the Nipa houses (Philippines) and the Nampan village (Myanmar). Moreover, this solution does not exclude the possibility that they add piles thrusted into the terrain to counteract a possible displacement of the structure and/or reinforce the structure, practice documented in ethnography (e.g. Lake Nokoué and Bajau Laut pile dwellings) (Fig.153).

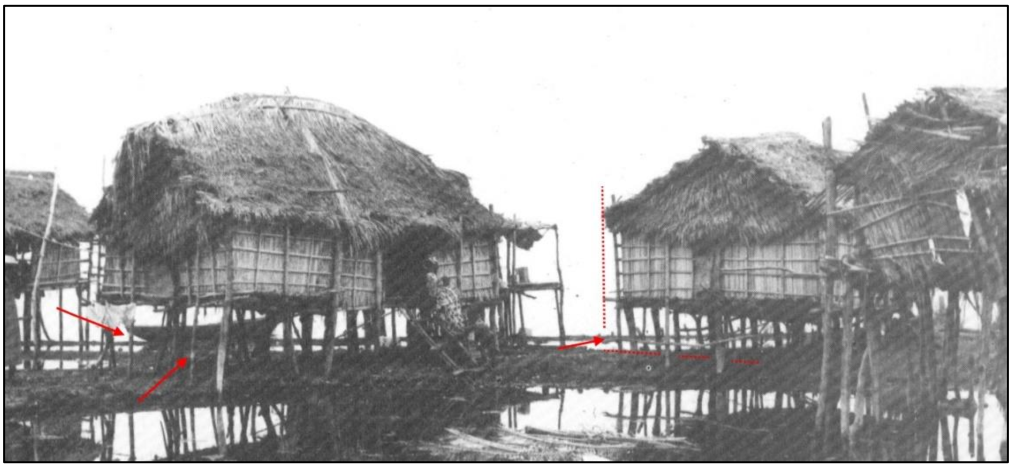


Fig.153: Reinforcing piles in a Hetin-Sota house, (Benin) (Pétrequin 1988).

Moreover, the occasional use of vertical elements as support would explain the absence of any identifiable alignments related with these walls.

Having weighed everything up, we concluded that this second hypothesis was the most plausible one.

4.3.3. Vertical Plan Sheathing

The task of the sheathing, both of the overhead plane and the vertical plane, is to define and enclose the house interior, granting a "safe area" protected from the weathering effects and other possible threats. The material and technique used to build the sheathing vary widely however, usually, in the most "primitive" settlements the local materials are used.

Finding traces of the original sheathing is very difficult especially in pile dwelling settlements. However, there are some fortunate cases: at Torwiesen, on the Federsee Lake, there are evidences that indicated that the walls were made wickerwork coated with clay (Dosedla 2016); at Dispilio, Grece, the wall were made of mud bricks (Touloumis and Hourmouziadi 2003); at See on Lake Mondsee, macrobotanical samples found, largely of fir, suggest that fir branches were used as insulation on hut floors and in the walls (Pawlik 1993).

At La Draga, in spite of other pile dwelling sites, no direct traces of the material used as vertical plane sheathing has been found. However, a huge quantity of oak's branches, some of them seemingly intertwined, has been found during the excavation. These elements have been interpreted as part of the sheathing, probably completed by the use of other local materials as fresh/dry aquatic/terrestrial plants and/or leafs.

From the archaeological perspective, as already mentioned above, different sheathing system have been found: bundles of local vegetal material like straw, reeds or unwind bark were probably used at Clairvaux; wickerwork coated with clay at Torwiesen; wattle-work both at at Misling II and Weyregg-Landungssteg. Ethnographically wise, instead, we have many examples. Among them, the already mentioned Nipa houses (Philippines), the Malay houses (Malaysia), the Nampam houses (Myanmar), the Hetin-Sota houses (Lake, Nokoué, Republic of Benin) and many others (Fig.154,155).

Fig.154: Sumbawa house sheathing (Indonesia) (http://trip-suggest.com).

Fig.155: An example of Nipa house (https://martinsazon.wordpress.com/category/hstarc4/).

These modern examples, among other things, can give us insights about the forms and the techniques used to build the sheathing. For instance, the sheathing techniques used in the building of the "Nipa house", a vernacular architecture of the Filipino houses, are very well documented and interesting. As can be seen in picture number (Fig.156), the technique changed according with the material used as sheathing and/or its forms (Sales 2013). These examples provide interesting elements for ethnographical analogy and can be used to shed some light about the ancient covering techniques.

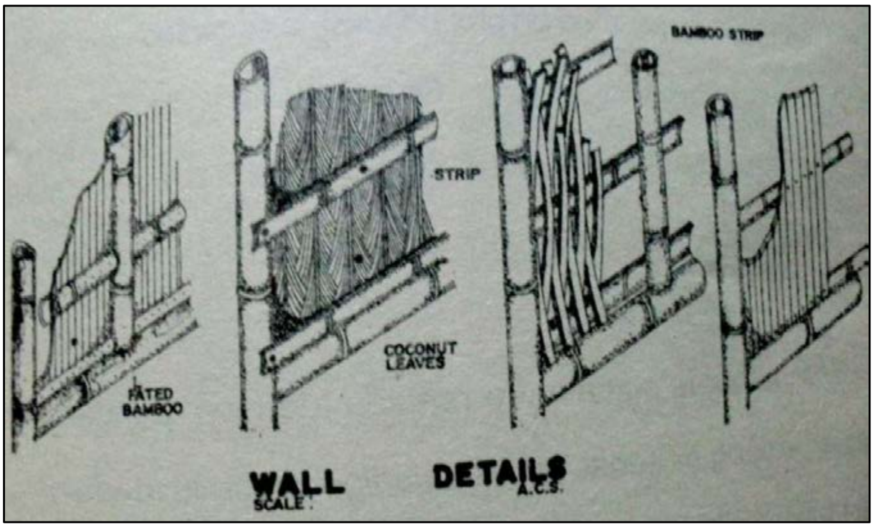


Fig.156: Examples of different types of materials used for walls in a bamboo Nipa hut (Sales 2013).

In all these cases, both archaeological and ethnographical, the roof and the walls sheathing was made using materials that can be found in the direct proximity of the house/settlement: bamboo, leafs, branches etc.

In our model, in order to reproduce de covering we had to use an approximate texture since it was the only one available in Rhinoceros 5. However, in the artistic reconstruction of the pile dwellings of La Draga made by Konstantin Nizhegorodov, and made starting from our model, a more realistic reconstruction can be seen (Fig.157).

Fig.157: The artistic reconstruction of the pile dwellings of La Draga made by Konstantin Nizhegorodov.

4.3.4. Vertical Plane Openings – Doors

The door is the link between inside and outside, and creates a relationship between different spheres. Together with the threshold, it denotes a significant crossing-place. In many cultures this transition from one space to another, which questions the physical presence of the person passing through the door, is accompanied by symbols (Van Gennep 1981; Deplazes 2008). What is striking is that, despite any hidden meaning, the door is almost always rectangular (Steadman 2006). This is because rectangular doors are the most practical of the options. People and the things we most often bring through doors benefit from the rectangular shape. Framing curves and diagonals is relatively complex to do. Moreover, construction materials throughout history have been either liner (wood, extruded metal parts, etc.), rectangular prism or cubic (cut stone, bricks, etc.) in shape. Using these materials, rectangular openings are the easiest outcome (Leyton 2003; Steadman 2006). Rectangles are also significantly easier to produce and install efficiently. In the case of pile dwellings the rectangular door is adopted since it can be easily obtained by exploiting the framed structure of the vertical wall that already provide two vertical piles that can be used as lateral elements for the door framing.

The door is composed by a door frame and a door panel. Usually, the door frame mark the limits of the door, has static functions and is were the door panel is attached. The door panel is the element that "close" the door. The most simple way to close the door frame is using a piece of hide, textile or vegetal elements. However, the most common is type of door the hinged, single-leaf door. Where the hinging system is absent, the door panel is simply leaned against the door frame.

Regarding the door location, it reflect the internal arrangement of the house but, usually is located in the centre of the front wall "*like the mouth of an animal placed in the middle of the face*" in the words of the famous Italian architect Vincenzo Scamozzi (1615). Whatever its position, its duty is to facilitate the communication with the inside (Gwilt 1851; Wilkes and Packard 1990; Oliver 1997).

At La Draga, so far, no direct evidences of doors have been identified, however, at least the presence of one opening acting as an main door can be suggested. As regarding its shape and materials, we have to rely on ethnographical analogy and archaeological evidences from other pile dwelling sites.

Archaeological direct evidences of doors in Neolithic pile dwelling settlements are very rare, therefore the comparison with other sites provides few information about the doors aspect, location, dimensions etc. Most of the information come from the house reconstruction. Sites as Clairvaux, Torwiesen II, Sutz-Lattrigen, Hornstaad Hörnle IA, Misling II, Weyregg-Landungssteg, Schärfling, Maharski prekop, Serteya II, Dispilio, shown rectangular doors closed in different ways (even if sometimes the doors has been built just as safety measure) but there are often based on analogy process rather than archaeological evidences. However, we have to mention two extraordinary exceptions: the door found in Zurich and the one found at Robenhausen.

Fig.158: The "Zurich" door (www.theguardian.com).

The door of Zurich (Fig.158) was in 2010 in Zurich and was related to a pile dwelling settlement on Lake Zurich. The door consisted of a frame composed by five criss-crossed elements (three verticals and two horizontal) holding three vertical wooden planks. The door was linked to the vertical plane by two hinges. The door was c. 1.52 m high and 90 cm wide. Dendrochronological analysis dates the wood to 3.063 B.C. that makes it one of the earliest doors ever uncovered in Europe.

The door of Robenhausenm (Fig.159) on Lake Pfäffikon, was found in in the nineteenth-century (Altorfer 1999).

The door was 1.60 m high and 0.65 cm wide, and was dated to 3700 B.C. The door was made of a single piece of split timber and it was attached to the door frame by four thongs, probably of leather.

These two examples seems to confirm the theory of the rectangular shape. Ethnographical analysis, on the other hand, provide us with more information.

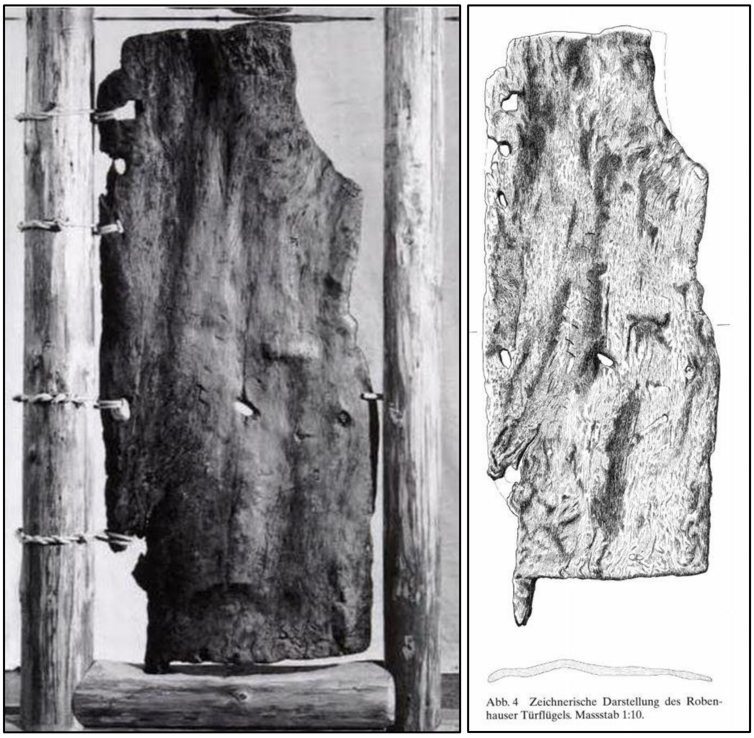


Fig.159: The Robenhausen door (Altorfer, 1999).

All the pile dwellings taken into account, have a rectangular door on the front wall (Badjao, Nampan village, Bajau Laut, Sumbawa, Tirap Nocte, Nipa house, Andak Endah House, the traditional Malay house etc.) (Fig.160).

Fig.160: In the Nipa houses (Philippines) the door are rectangular and usually made of bamboo elements (https://martinsazon.wordpress.com/category/hstarc4/).

In some cases, a secondary door appears on the other walls (e.g. Lake Nokoué, Bajao Laut, and Nampan). The doors are closed with pieces of textile (e.g. Badjao, Bajau Laut, Irrawaddy delta) or using a small panel made of local wood, leaves or other vegetal elements (Tirap Nocte, Sumbawa, Rawang, Nipa house, Zancudo birmania, Myanmar). Based on architectural, archaeological and ethnograpical data, it seems quite possible that also at La Draga the doors frames were rectangular (Fig.161). Moreover, this form could be easily obtained by exploiting the framed structure of the vertical wall: two vertical piles could be used as lateral elements for the door frame while a third elements acting as "lintel" (but without any structural role) could be added just by tying a horizontal branch between the two vertical sides of the door. Regarding the door panel, we can postulate that was made of a piece of hide or using a single-leaf door made of branches, leaves or other elements of plant origin.

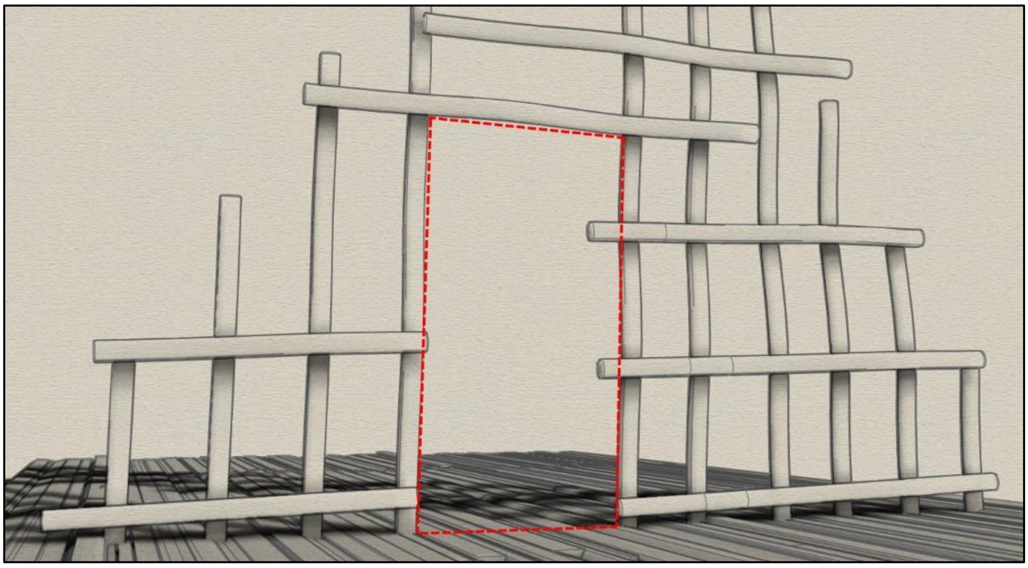


Fig.161: Reconstructive hypothesis of the door frame and its location on the vertical plane (model by the author).

4.3.5. Vertical Plane Openings – Windows

A window consists of a frame and a panel meant to close it. In its simpler form a window could be a simple hole in the wall without frame or panel. The main role of the window is to let in light and air. As for the door, the most common shape for the windows is the rectangle. As we said, this is because rectangular doors are the most practical of the options especially using material as wood and primitive technologies and rectangles shapes are significantly easier to produce and install efficiently. (Leyton 2003; Steadman 2006).

At La Draga, there are no evidences of windows and the presence of any apertures acting as windows can be only assumed. In fact, while an aperture acting as door is essential, the presence of windows is by no means self-evident. Archaeologically wise the information about pile dwellings windows are extremely scarce. In almost all the sites analysed in this research (e.g. Clairvaux, Torwiesen II, Sutz-Lattrigen, Hornstaad Hörnle IA, Misling II, Weyregg-Landungssteg, Schärfling, Maharski prekop, Serteya II) the windows has been reconstructed as trapezoidal/triangular and located at the junction between roof and frontal/posterior wall (Fig.162).

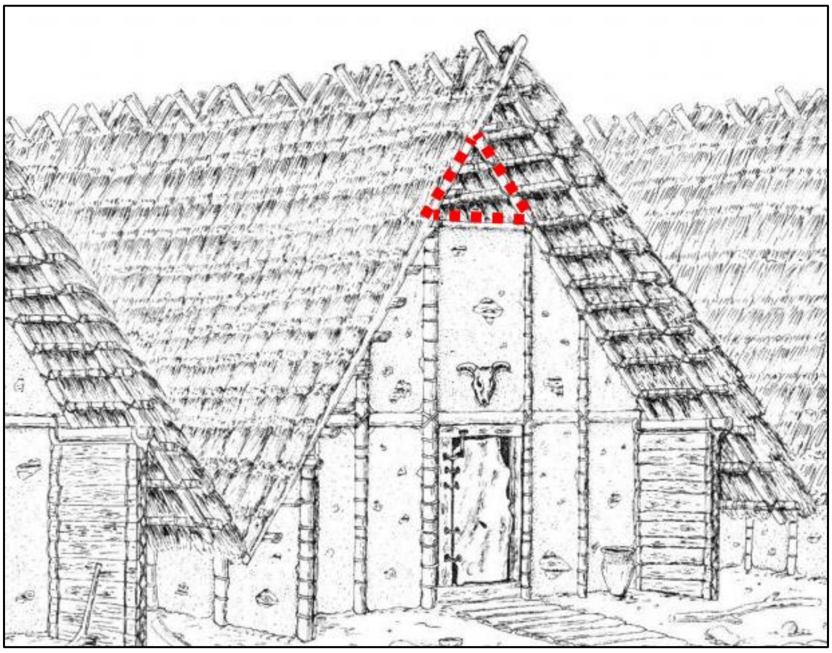


Fig.162: The Robenhausen house "window" (Altorfer, 1999).

However, usually, is not clear whether this is the result of a deductive process based on archaeological evidences or the results of a comparison with ethnographical examples.

Ethnography provides more information about the windows (e.g. Badjao, Nampan village, Bajau Laut, Sumbawa, Tirap Nocte, Nipa house, Andak Endah House, the traditional Malay) (Fig.163).

Fig.163: Sumbawa houses (Indonesia) in case of necessity holes can be easily obtained piercing the walls made of bundle of reed (http://muhamadyasid.blogspot.com).

Despite difference in climate, materials, technologies etc. four are the most common type of windows in pile dwellings: no windows at all; simple holes into the wall sheathing; rectangular windows along the walls; triangular/trapezoidal windows at the top of the frontal and rear walls at the junction with the roof.

The pile dwellings taken into account possess the same basic architectural features hypothesized for the houses of la Draga: wall/roof consisting of a frame with criss-crossed elements and sheathing of natural vegetal elements. This led us to consider the possibility that at La Draga one of these kind of windows was used. However, we have no way to say, definitively, witch one was indeed used. Particularly interesting is the hypothesis that there were no windows at all. Ethnographical analogy has shown that in many cases (e.g. the Paniduria Nocte; Afari Trine house, Sumbawa houses) simple houses with walls made of vegetal elements have no needs of openings since the smoke simply goes out through the wall sheathing (Levy *et al.* 2004) (Fig.164).

Fig.164: Sumbawa houses (Indonesia): these houses usually have no openings except for the frontal door. In case of necessity, holes can be easily obtained piercing the walls made of vegetal elements (https://alanmalingi.wordpress.com).

The absence of opening also diminishes the loss of heat. Moreover, in case they needed an opening, the composition of the walls would allow them to obtain a hole in it. I am incline to consider this solution (no windows) as the one used at La Draga especially since one of the houses taken into account, the Sumbawa house, share the same A-shape hypothesize for the houses of La Draga ans show no windows. Still I want to stress that there is no way to knew what really was the windows shape.

4.3.6. Vertical Plane Dimensions

We have no direct information about the dimension on the vertical plane of the houses at La Draga. However, we were able to make a hypothesis using the dimension obtained for the other planes and their elements. In order to calculate the high of the vertical plane we calculated the distance between the base plane and the point where the tilted elements of the overhead plane (or roof pitches) interested. The results was a high of 2.30 m (Fig.165,167).

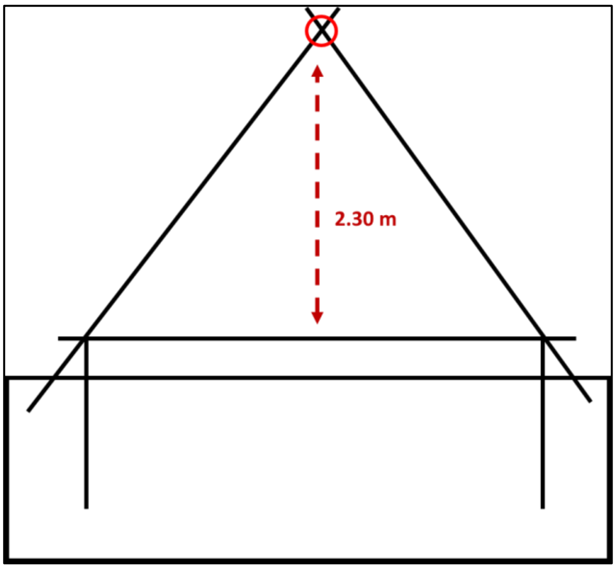


Fig.165: La Draga house inner high (image by the author).

Instead, in order to estimate the width of the vertical plane we took into account the point of intersection between base plane and overhead plane, that is where the base plane ends and the interior space of the house begins. We measure the distance between the roof pitches at the intersection point with the base plane and calculated a base width of 2.74 m (Fig.166,167).

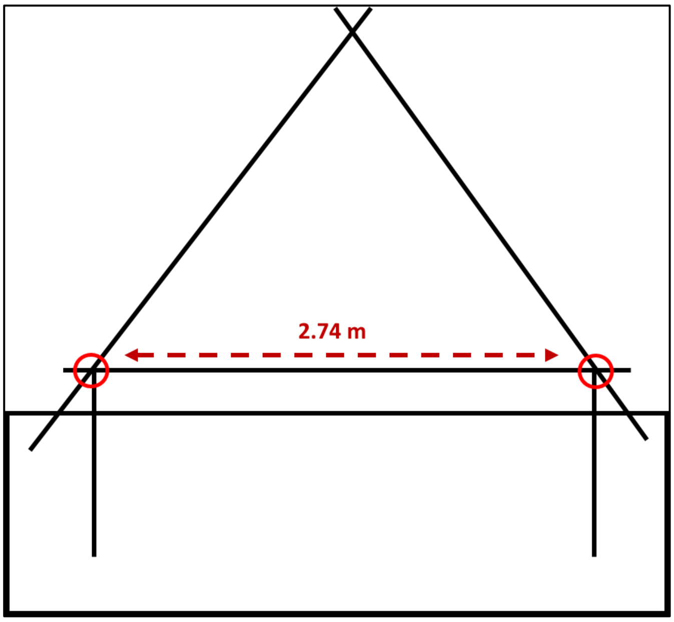


Fig.166: La Draga house inner width (image by the author).

If compared with other pile dwellings, the width of the interior space of the

houses of La Draga seems to be smaller (Maharski prekop 3.5 – 4.5 m; Serteya II 4.5 m; Torwiesen II 3 – 5 m; Clairvaux 4 m; Sutz-Lattringen 4.5 – 5 m; Niederwil 5 m). However, in many cases is not clear if the width refers just to the house interior or to the width of the entire platform on which the house rest. Some reconstruction seems to indicate that there was a slight difference between platform and interior of the house (like at Torwiesen II). In this cases the width calculated at La Draga seems to fit with some of the other houses.
Regarding the high of the house we cannot compare our result since we have no information about the possible high of the other houses.

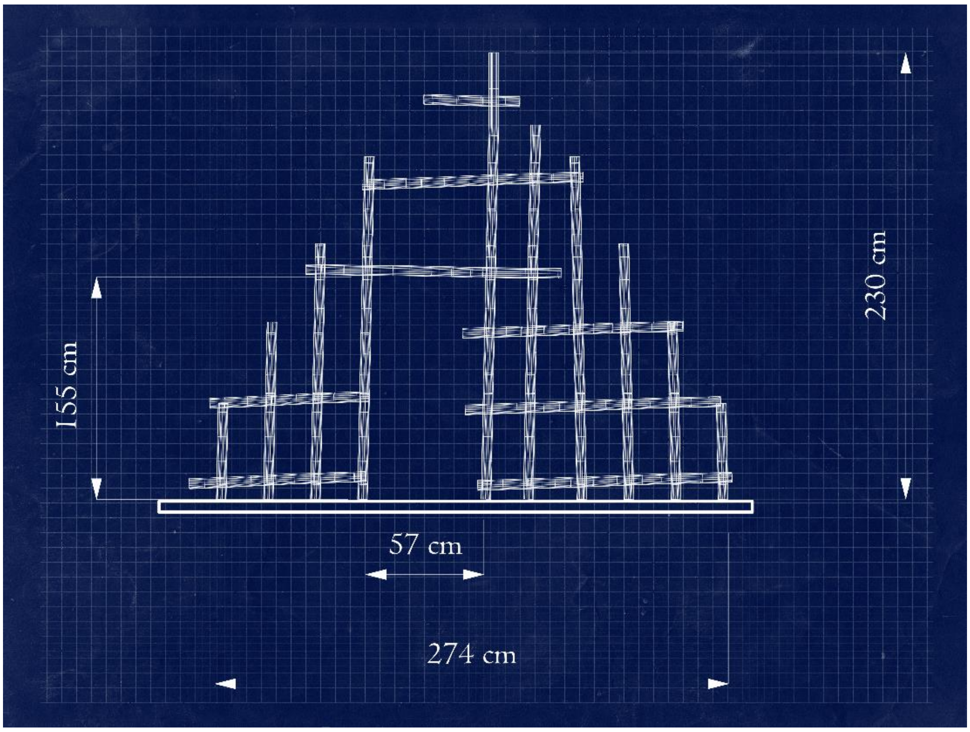


Fig.167: Blueprint showing the vertical plane dimensions (blueprint by the author).

4.3.7. Vertical Plane Connections

Although both rolls of lianas and ropes made of thin twisted fibres have been recovered at La Draga (Piqué *et al.* 2016) (Fig.168), there are no evidences that they were used as connections to tie together the different elements composing the vertical plane nor we have evidences about how its different elements were tied together and to the other house planes. However archaeological and ethnographical comparison seems to indicates that lianas and ropes were indeed used to connect the various parts of the vertical plane.

Fig.168. Top: A piece of rope from La Draga. **Bottom:** A lianas bundle found at La Draga (images from Bosch *et al.* 2006).

Evidences of lianas and/or ropes tying together the various elements of the base plane have been collected from several archaeological pile dwelling sites (e.g. Serteya II, Clairvaux, Sutz-Lattrigen, Riedstation, Hornstaad-Hörnle IA). However, these evidences are often fragmentary and give us little information. Ethnographical analogy, on the other hand, display both the use of natural fibres (in different forms) as connection and can give us an indication about how these connections were used in the past. All the modern pile dwellings taken into account (among the others: Lake Nokoué; Bajau Laut; Badjao. Tirap Nocte etc.) shown the same solution: the crisscrossed elements of the wall framing were tied together with different types of natural fibres (replaced, in some cases, by strings of modern material like plastic ropes) (Fig.169). The framing was attached to the rest of the house in the same way and it acted as base for the sheathing. Usually the vertical elements rest on the house floor (base plane).

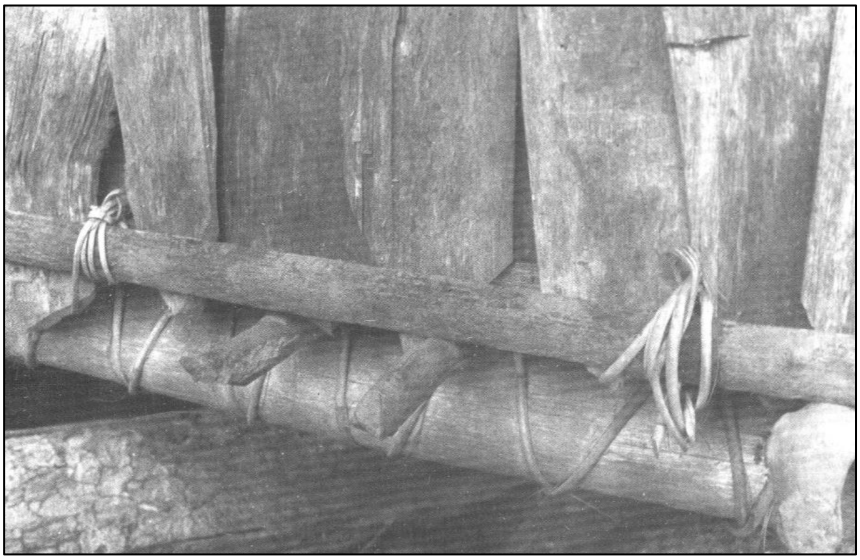


Fig.169: Darai house (Indonesia). The base plane and vertical plane elements are connected using ropes made of natural fibres (Pétrequin 1988).

4.4. RELATIONS AMONG THE DIFFERENT PLANES ELEMENTS

The house, as a complex, forms a unique object but it is composed by several other individual or conglomerated elements. The identification of these elements will allow us to identify the structural parts and to work with these. Following the architectural scheme, and starting from the below, we can identify:

- **Base Plane**, composed of:
    - **Ground**: in pile dwelling architecture the ground is a fundamental element. Housing the forks allows the entire structure to stand. At La Draga, the clayish ground represents, and acts, as an individual element.
    - **Posts holes**: the holes made by the action of inserting the forks

and the posts inside the soil. There were no holes made before the construction to house the posts.

- **Forks**: the first element of the base plane. Each of them is a single element who can stand alone. However, in the base plane they act altogether as a unique element meant to hold the base plane and the entire weight of the house.

- **Base Framing**: it forms the second part of the base plane. At La Draga, the framing was made of beams, planks and logs lying criss-crossed on the forks and holding the floor. The single wooden elements of the base framing cannot stand alone as independents: is the sum of the different parts that create a unique element.

- **Floor**: is the third and last part of the base plane. The forks and the base framing hold it but it is tied only with this last one (or just lean on it). The floor was made of wooden planks and beams. Some of the planks had triangular section, due from cutting logs with stone wedges. As for the base framing, the single parts of the floor cannot work as single element but they act altogether forming a unique element.

- **Overhead Plane**, is composed by five different elements that act together:

  1) **Main forks**: the two forks, one on the front and one on the back of the house, meant to hold the ridge beam.

  2) **Rafters**: these long beams were stuck into the soil and positioned obliquely to create the two the roof pitches and the lateral walls. Being plunged into the soil, they could stand alone as independent element. At La Draga they act as main support for the purlins.

3) **Purlins**: a series of beams lying perpendicularly to the rafters, with whom create the framing meant to support the sheathing of the roof. They could not stand as an independent element but have to be linked with the rafters.

4) **Ridge beam**: a horizontal beam that link the two extremity of the house and on which lay all the rafters. Even if this element is a principal one, it cannot stand alone but has to be held by the two main forks.

5) **Sheathing**: was probably made of branches and leaves of different plants (like bulrushes), probably tied together to form bundles. The sheathing cannot stand as individual element but need the roof pitches to be held in site.

- **Vertical Plane**, was composed of

1) **Vertical plane framing**: at La Draga, due to the particular house form, there was just two vertical walls, one on the front and one on the back side of the house. These walls were probably made of a framing system made of criss-crossed wooden elements. The vertical walls elements cannot stand alone as independents elements: they rest on the base plane and against the main rafters to which they were tied.

2) **Sheathing**: was probably made of branches and leaves of different plants (like bulrushes), probably tied together to form bundles. The sheathing cannot stand as individual element but need the roof pitches to be held in site.

Starting from the description of the key elements described above and from general characteristics of them, a model of the structure of cabin of La Draga has been proposed (Fig.170).

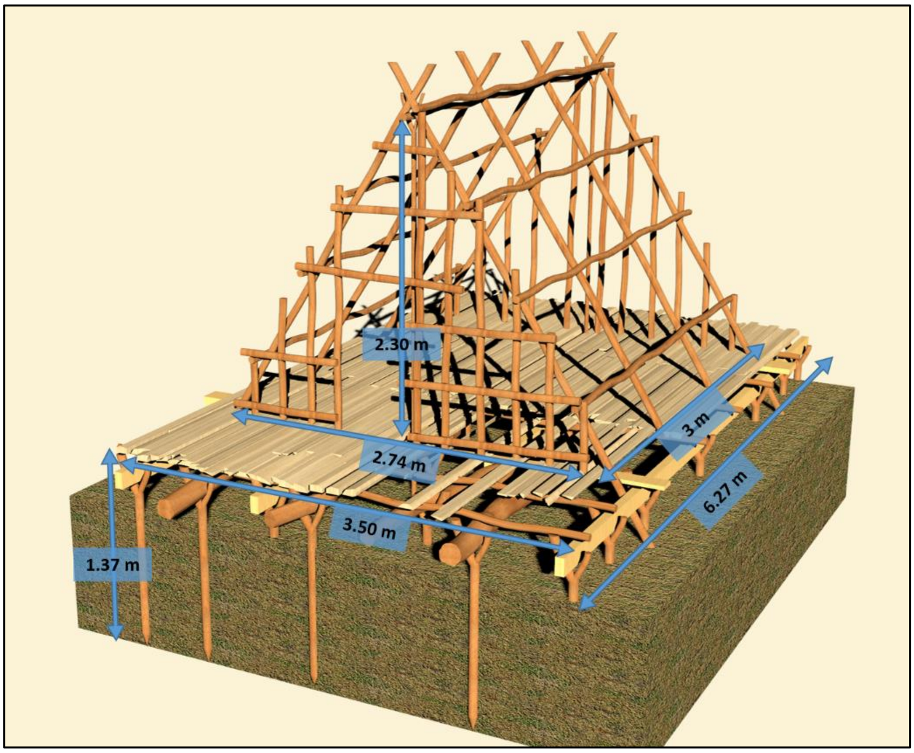


Fig.170: The overall dimensions of the house of La Draga (model by the author).

4.5. THE OVERALL HOUSE FORM: THE A-FRAME HOUSE

Very few is known about the structure of the ancient cabins especially for their upper parts (walls, openings, roof etc.). Nevertheless, it is possible to attempt to produce a viable reconstruction mixing the data coming from the archaeological researches, the data from other pile dwelling sites and 3D technologies.

Once we created a 3D version of the architectonical elements, we began studying all their possible arrangements. As said before, despite the scientific value of the archaeological data, the information about the architecture were scarce. Our conclusive hypothesis, as it has been said before, is a cabin with the following structural features:

- A **base plane** made of short forks jutting out from the soil about 30 cm and holding a framing composed by planks, piles and trunks. These two elements were meant to hold the house floor made of planks and branches.

- A **vertical plane** consisting of two vertical walls, one in the front and one in the back of the house.
- An **overhead plane** made of two lateral roof pitches acting also as lateral walls. The roof pitches consisted of tiled elements plunged into the soil and horizontal elements lying on them forming a framing for the sheathing.

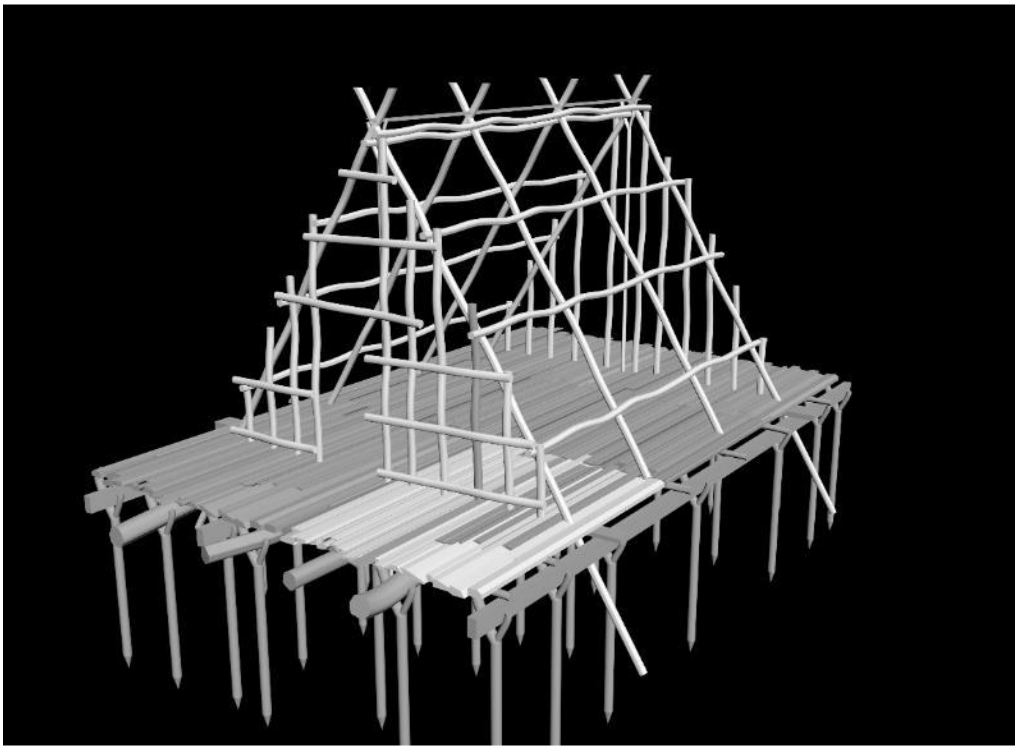


Fig.171: Representation of the structural feature of the houses at La Draga (model by the author).

However, the external appearance of the cabin remains unknown. To compensate this missing information we have used other archaeological reconstructions as well as ethnographical analogy. We have looked for coincident features that could be fit the data. Once we found a compatible feature, we re-elaborated it following our evidence, in order to create an original form fitting with our site and our data.

According to the features documented and the architectonical elements our

A-Frame House

An A-frame house is an architectural house style featuring steeply angled sides (roofline) that usually begin at or near the foundation line, and meet at the top in the shape of the letter A. An A-frame ceiling can be open to the top rafters ("A-frame" Oxford English Dictionary Second Edition on CD-ROM (v. 4.0) © Oxford University Press 2009).

hypothesis is that the cabins would be similar to which is known in architecture as A-Frame house (Fig.171). The main characteristic of this typology of houses is that that the tilted roof pitches work as well as lateral walls, giving to them the peculiar shape of an A. The only vertical walls are the frontal and the rear ones. The outcome was an A-Frame pile dwelling, with tilted lateral walls, standing on short forks holding a framing of horizontal elements supporting the house flooring made of planks and beams, which was not too much raised from the natural soil (30 cm c.) (Fig.172).

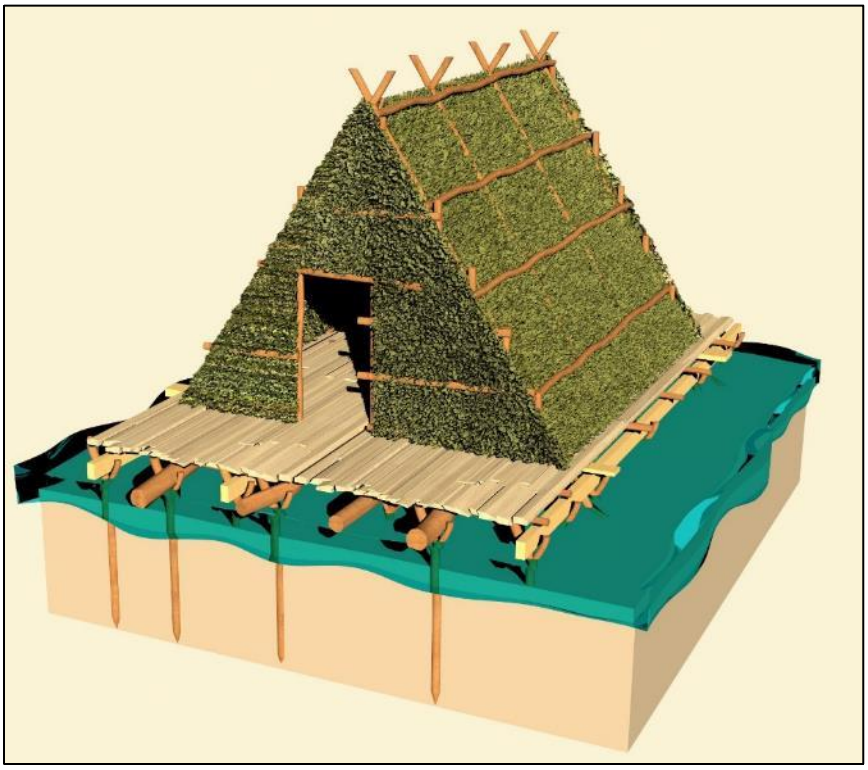


Fig.172: The A-Frame house of La Draga reconstructed using Rhinoceros 5 (model by the author).

The front wall and the back wall were vertical and probably they rest on the floor and against the tilted walls.

5

A DEDUCTIVE APPROACH: PLANNING A BIM PROCESS FOR LA DRAGA

“*The biggest thing about BIM is that it’s moving us back to interdisciplinary work.* „

KATHLEEN LISTON

FOREWORD

Usually the BIM process is used to manage the information about a standing structure, to describe its characteristics, its needs and the information about it. At La Draga we faced the problem of not having any standing structures but only parts of probable structures. Because this is a common problem in archaeology, we decide to plan a BIM process meant to compensate that. The solution was creating a process showing both the material data, the archaeological evidences, both the reconstruction and the hypothesis about the lost elements. The result would be a BIM that, beside the “common” information, could displaying a 3D model showing the “certain” elements and the “hypothesized” ones. To generate our BIM process we decided to use Rhinoceros 5, Grasshopper and VisualArq. The objective of this case study is to design a procedure to build a parametric and informed 3D model of a Neolithic pile dwelling. The following section describe the procedures undertaken so far to construct the BIM process (Fig.173).

5.1. CONSTRUCTIVE PROCESS

The first step is the drawing on the XY plane of the polylines representing the overall size of those architectonical objects forming the architecture (Fig. 174); in the case represented here:

- The outer line represent the perimeter of the elevated platform;
- The central line defines the boundary of the posts and the connected framing (or framing);
- The inner line represents the perimeter of the walls.

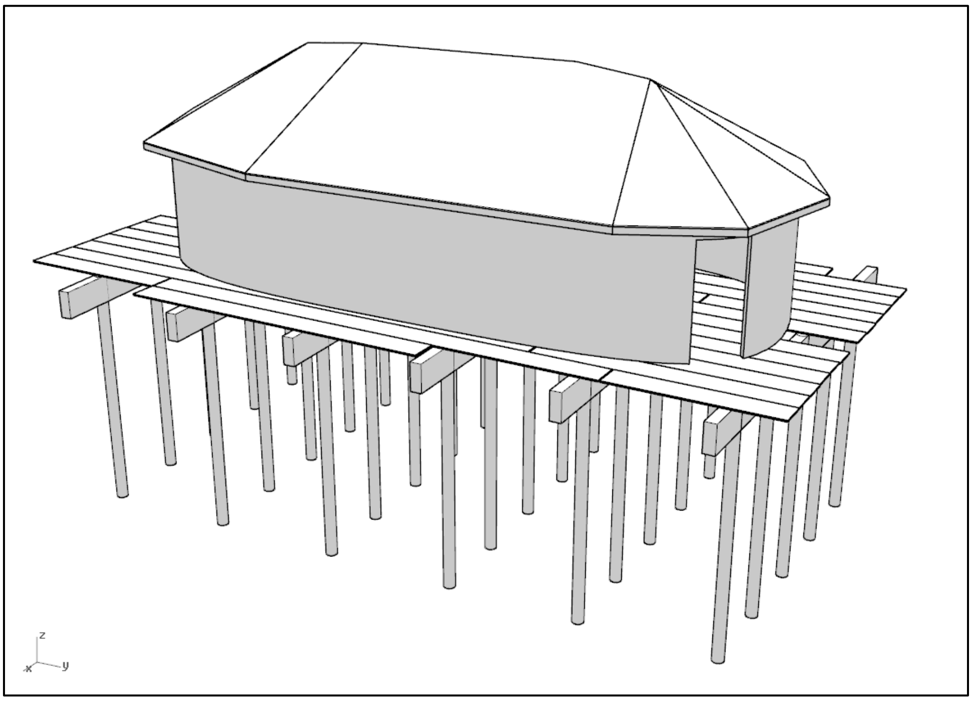


Fig.173: An example of possible pile dwelling obtained inside the BIM (image by Calvano).

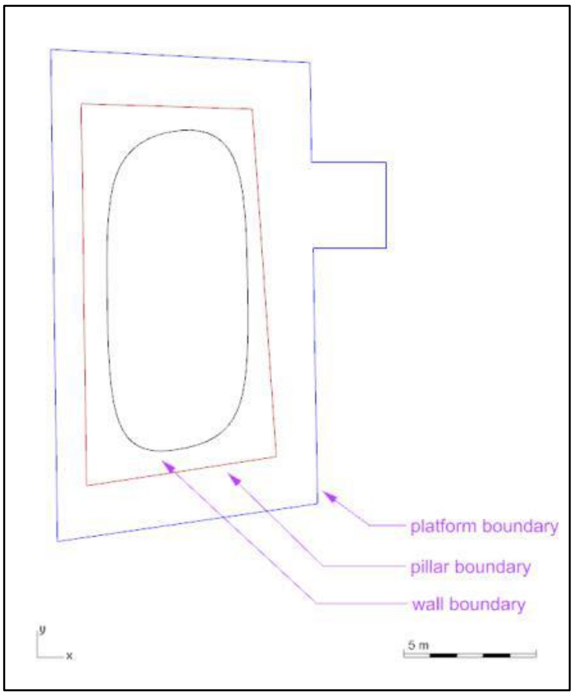


Fig.174: The different boundaries used to define the house blocks (image by Calvano).

5.1.1. Building The BIM Process

The definition of the algorithm (Fig.175) begins with the construction of primitive lines to which the architectonical objects “posts” and “beams” (1) will be linked. Then we built a surface starting from a closed plane curve (2) and we move this surface upwards respect the variable parameter h_pillars (3). The surface in eighth is divided with variable parameters alongside the parametric direction u and v generating a points matrix identifying the positions of the cabin posts (4).

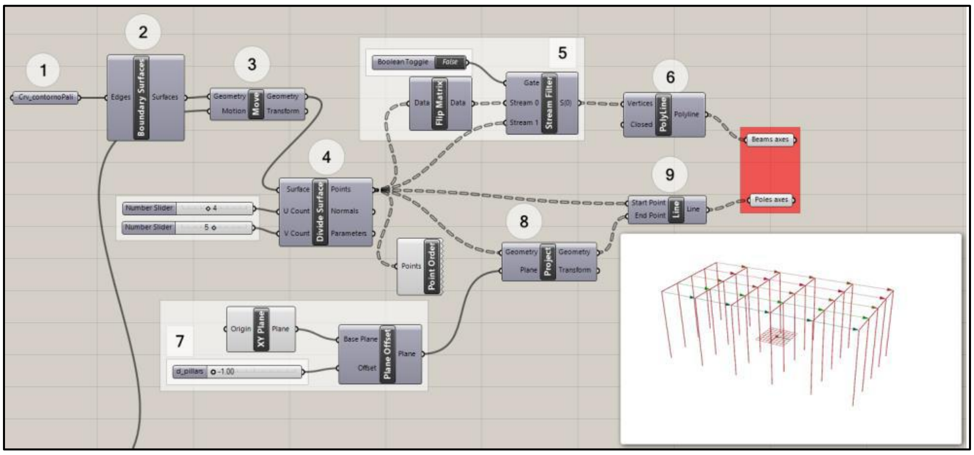


Fig.175: The BIM constructive nodes (image by Calvano).

The element SDivide, used to create unidimensional geometrical entities, determines a points matrix whose data structure offer the clear distinction of rows and columns. The structure rows/columns could be inverted using a Boolean switch that using the transition from true to false, and vice versa, allows a data filter to select one of the two possible built (5). Through the points sequence we built the polylines that are the structural joists axes (6). The pile dwelling posts went through the water and the soil. This detail is expressed by the definition with a negative offset in the horizontal plane, that from height 0 descend about a variable value d_pillars (7). On the moved horizontal plane, the points matrix is projected (8); projected points and quoted points- punti in quota began the extremes of vertical lines and structural posts that will held the pile dwelling platform (9).

5.1.2. Architectonic Object Style Definition (Family)

The external geometries and the definition illustrated above represent the forms on which lean the architectonical objects. In first place, the style of those architectonical objects that will be inserted into the model for its characterization should be defined. To do so we used VisualARQ. In VisualARQ, when clicking with the mouse right button on one of the architectonical objects, a "Style" window, containing a list of some pre-defined styles, will pop-up (Fig.176). This window also offers the possibility to duplicate an existent object or to create a new style. By clicking "New", we will create a new style. The path considers, at the beginning of the customization, the creation of those functional elements of the object; the next step is the compilation of the graphic attributes of views and sections, the selection of shapes and dimensional characteristics and the definition of numeral and textual metadata, handled by the tool “Parameters”.

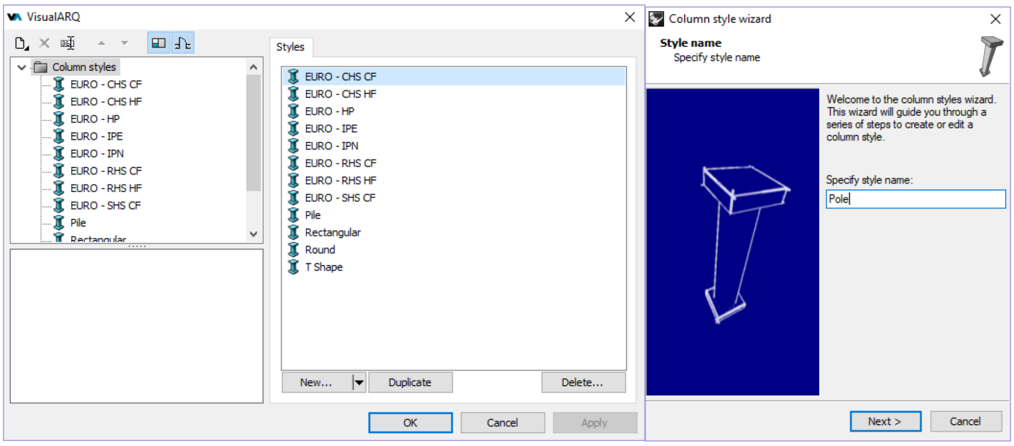


Fig.176: How to create a new family (image by Calvano).

In this way is it possible to create families made of architectonical objects to link to the primitive forms/shapes. We illustrate, as an example, the customization of the pile dwelling posts. Right-click on the VisualARQ object called “column”.
In VisualARQ, right-clicking on the object “column” will open a window showing some pre-determinate posts styles. In this window, we click “New” and then “Column Style”. Here we have to decide the new style name, in our case “Pile” (Fig.176).
The following windows allow choosing the post section, among some forms made available (Fig.177), and then we have to set the radial dimension of the chosen circular section. There is, in addition, a window that allow to replace the views floor and perspective respectively a 2D block and a 3D block. The last window is a preview of the built model.

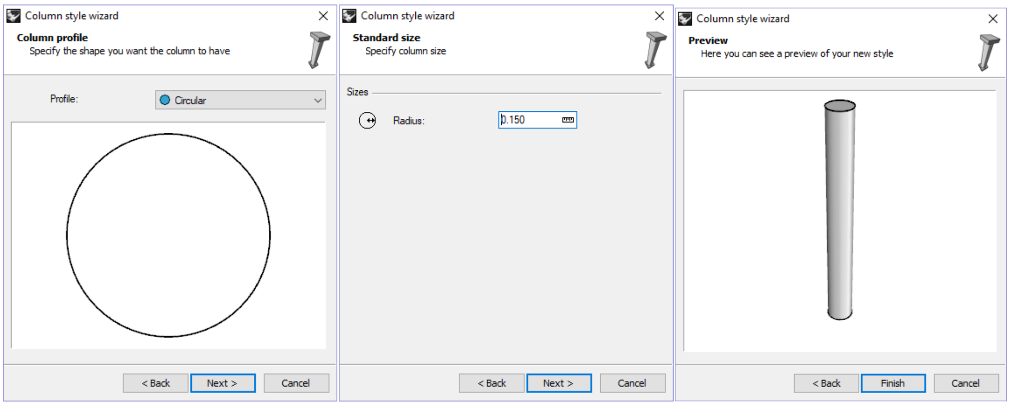


Fig.177: Creating a new object and its characteristics (image by Calvano).

The next step is a series of settings, which in some cases reiterate the actions just described, about the architectonical object Style: in the section "Actributes" we can set the starting layers, the visibility and the materials; in the same window we found the graphical variables to handle the representation of the projection and of the architectonical object section.

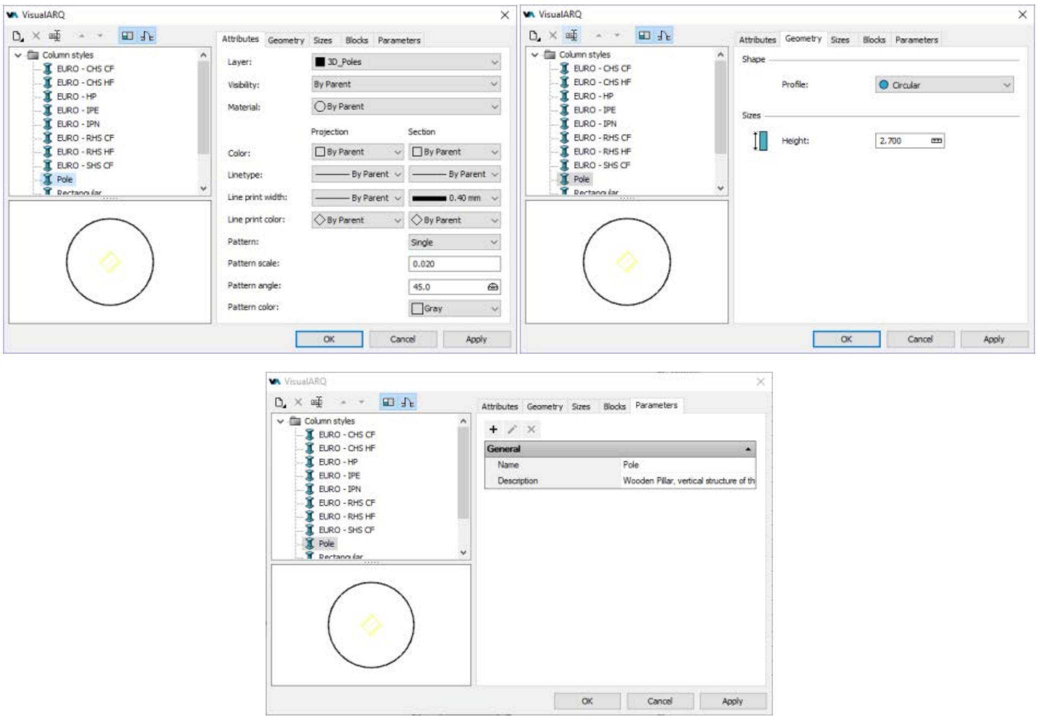


Fig.178: Defining an objects and its attributes (image by Calvano).

In the section "Geometry", we have to choose the kind of section outline to be used in the style section and an object default height. Once we have defined the shape, in “Size” we can introduce lists of dimensional variables in order to be able to define the family “Post”, using pre-determined dimensions. In “Blocks”, you can replace no-parametrized blocks in the 3D and 2D visualization. “Parameters” is where we can set the metadata characterizing the style that we are creating. The metadata can be textual or numerical and are shown/presented in a window were we have to define: Name, Category, Data type and Description (Fig.178).

5.1.3. From Geometry To The Architectonical Object

Once we have defined the style of the architectonical object we have to create it and link it with the geometries defined at the beginning of the parametrical procedure (Fig.179).

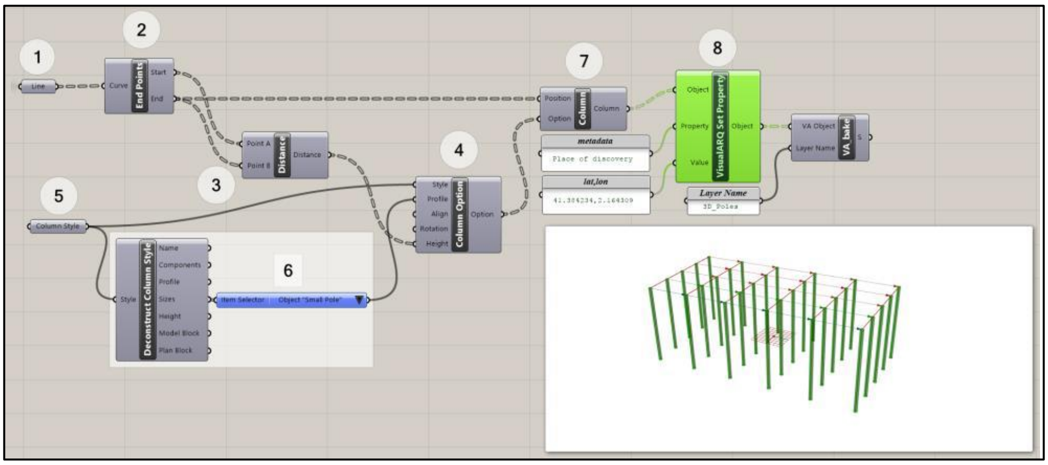


Fig.179: Controlling the object using the nodes (image by Calvano).

To do so we get again the posts axes (1) and we extract the end points from them; the distance between the two ends defines the high of the post, the value of which is a variable to be included in the component that collects the options with which determine the architectonical object being created (4). Another input data of this component is the style that was previously created (5) from which extract one of the dimension set during the style building phase (6). The options then will characterize the object “post”, the position of which is defined by the end point of the line representing the axe (7). The next component allows to recall the metadata set during the style definition phase (Place of discovery) and to give it a value that will be upload directly into the final architectonical object (8). For the construction of the objects “beams”, the procedure is the same (Fig.180) but, in this case, we decide to create the style using Grasshopper using VisualARQ components devoted to building the style (1). The visual programming allows defining a section using custom measures (eg. A, B, C) and metadata directly set in the definition (eg. Place of discovery). Also for the beam the component Beam Option (2) will have as input the Style just defined and one of the components of the profile (eg.B).

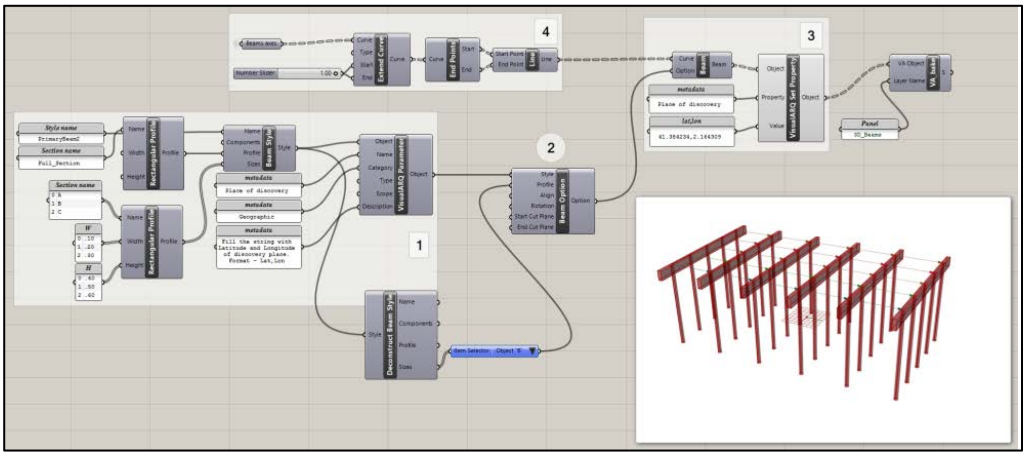


Fig.180: Controlling the object using the nodes (image by Calvano).

The component Beam (3) will be then connected to the options and to the primitive geometries accordingly edited for a technical adaptation (4); the component Beam, like the component Column, could be informed with defining metadata (eg. Latitude, longitude etc.).

The platform (Fig.181,182) is characterised by a surface placed at the desire quota (1) and divided in order to represent the random juxtaposition of the wooden tables (2).

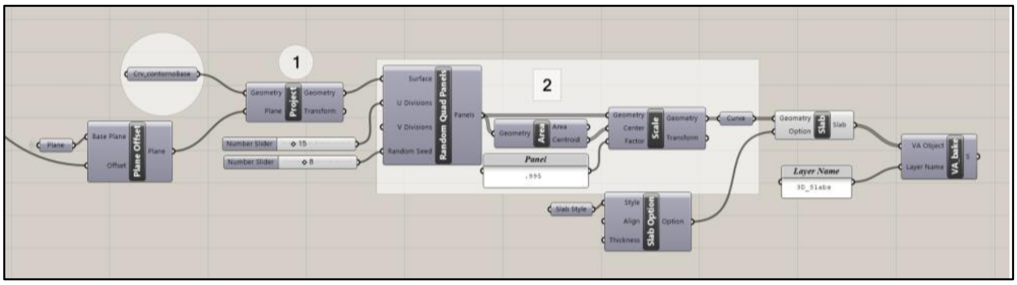


Fig.181: The nodes relate to the component "Beam" (image by Calvano).

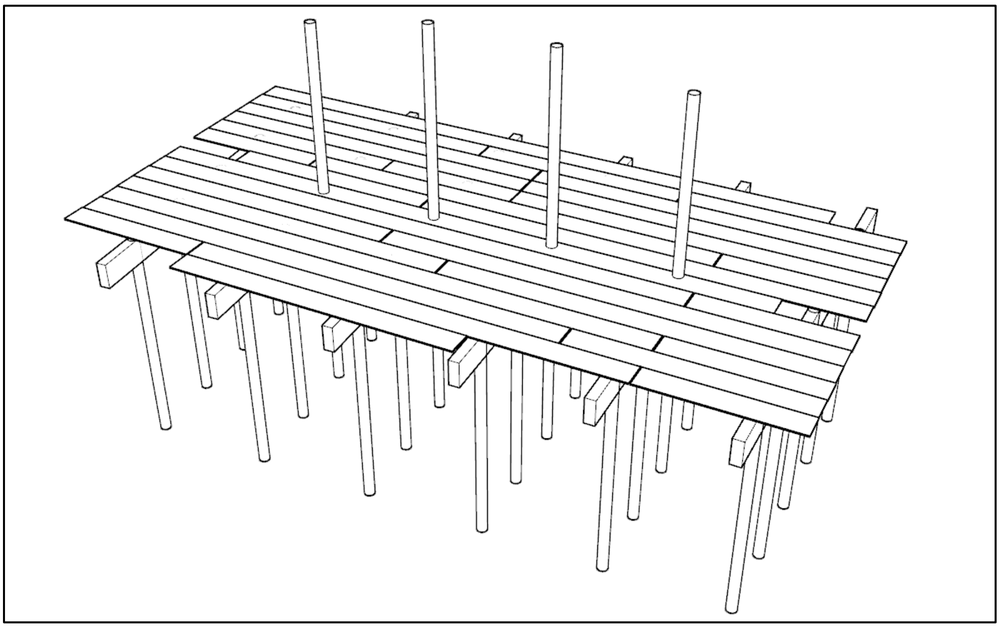


Fig.182: Combining components using nodes (image by Calvano).

The walls are placed on the platform by connecting them to a component that allow us to modify the form in the plan (or top view). Figure 183 shows how is possible to switch easily from a curved from to a polygonal form without interruptions, guarantying infinite shapes and increasing the number of architectures included in the definition.

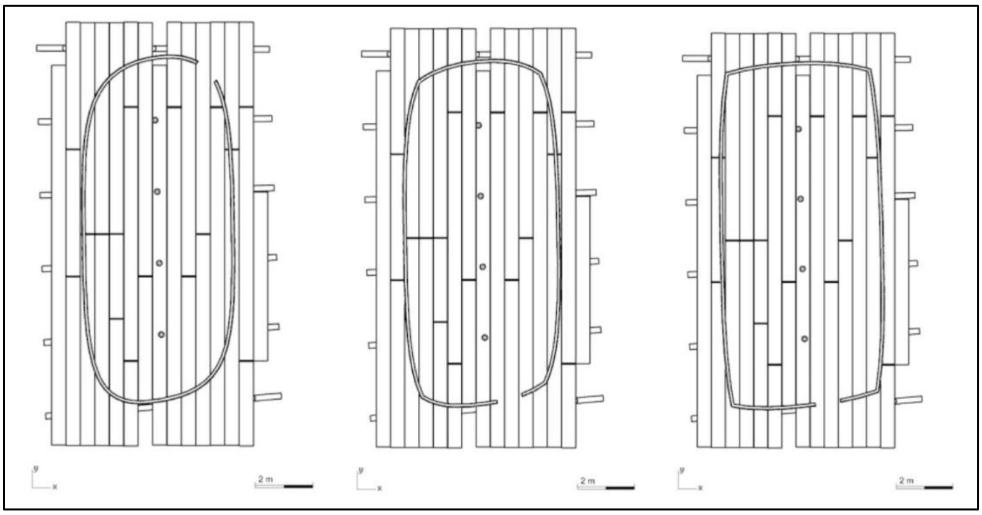


Fig.183: Changing the value we can immeadiately and easily change the aspect of the different components (image by Calvano).

The covering (roof) follows the form drawn in the plan and, thanks to an open parameter, is possible to change, automatically or by input, the slope of the pitches.

6
CONCLUSIONS

> "*Every new beginning comes from some other beginning's end.* „
>
> SENECA

The interpretation of the archaeological evidences is the key to understand ancient society: how they lived, how they built, how the thought and so on. That is why we archaeologists are always looking for new methods and tools allowing us to better understand the data we recollect during the excavations. This is exactly what we did at La Draga: because the conventional ways of investigation were not enough to decipher the data about the pile dwelling structures we decided to try a new approach, a new method, by using the tools provided by the Virtual Archaeology. As result, we have been able to produce the first reliable and accurate reconstruction of these houses since the discovery of the site and, most important thing, the model presented here is the one that, so far, more closely follows the archaeological data and best fits to them.

However, even if the house reconstruction was the main objective, it has not been the biggest achievement of this research. In fact, without taking anything away from the importance of the reconstruction, it is strictly bound to the site and works just for the site of La Draga, it has no "universal" value. On the other hand, the proposal of analysing buildings using an innovative ontology based on modern architectural definition of house parts, the description of the physic "behind" the pile dwellings and the creation of a BIM that would fit not only with the site of La Draga but also with all the archaeological sites in general, had a most wider value providing useful, and in some case essential, tools. These are the real achievements of this research.

The use of architectural definition and the subdivision of the buildings into planes works as "Munsell table" providing the archaeologists with a tool that not only gives a specific terminology to use but also help in define and interpreter the house parts. In our case, we were able to define the house planes (base plane, vertical plane, overhead plane) and their key elements and this helped us in the reconstructive process.

If the architectonical principles are essential to define uniformly the ancient buildings and their parts, be aware of the physic around the pile dwellings is essential for the purposes of reconstruction. The physic principle should be taken into account every time a reconstruction is undergone: they can make the work harder but, first of all, they reduce the possibility of errors. Oddly enough, both architectonical principles and ontology and physic principles are rarely taken into account and even more rarely described when a reconstructive process is illustrate. Obviously, sometimes, the grade of preservation of the archaeological evidences is such that these principles cannot be used. However, there is no reason not to use the specific terminology and to keep in mind the architectonical and physical principles that, if they cannot be used directly, can at least provide "boundaries" to our reconstructions.

For this reason we decide to do a first step in this direction and placing these "bundles of notions" inside this research, in a manner that they can be used, as we did, as "guidelines" for other reconstructions or, at least, give a sense of what is necessary to provide a reliable reconstruction.

Regarding our reconstruction, the first step was to create a virtual version of the architectonical wooden elements found at La Draga. Then we started to investigate all the possible architectonical arrangements fitting the archaeological data we had. The program used to undergone the reconstructive process is Rhinoceros 5. We chose this program because it is a very good mid-point between CAD programs and complex 3D modelling programs like 3D Studio Max, Maya or Blender. Moreover it has almost endless plug-ins that, basically, allow you to do whatever you want and, again, it is compatible with Grasshopper and ArchiCad, that are the other two programs we used to create the BIM process.

In order to ensure that the reconstruction was as accurate as possible we also included in this process the data we gathered studying the modern pile dwellings and the technologies used to their construction and the physical forces acting on this kind of structures and the related problems.
It is important to point out that these data, even if coming from the study of modern structure, are still relevant for two important reasons:

- Even if the machinery is more developed and the materials used in the house construction could be different, the basics technique and principles behind the construction of a pile dwelling are still the same.
- The physic forces involved are the same, because the laws of physic do not change in time, they are immutable.

However, even combining these data with the archaeological ones some aspects of the houses remained unclear. In order to compensate this trend, to "connect the dots", we decide to use both archaeological and ethnographical analogy. We use the information coming from both other ancient pile dwellings settlements, in first place the Neolithic ones, and the information obtained from the study of those human groups that still lives in pile dwellings, especially those groups using simpler structures.
As said above, we use this data to try to "fill the gaps" in our reconstruction but, instead of just "cutting and copying" the parts we needed, we used these data as "hints" about the missing parts and the building solutions who could be possibly

been used at La Draga.

Both these data and these procedures allowed us to narrow the number of possible reconstructions. Our final deduction has been that the pile dwellings of La Draga would fall within the A-Frame house typology. Its unique shape is due to the fact that the roof pitches were tilted and worked as well as lateral walls, while the only vertical walls are the frontal and the rear ones as shown in detail in chapter 4.3.

Using the terminology and procedure borrowed from modern architecture, we subdivided the house in three planes, each ones with its specific components: base plane, overhead plane and vertical plane.

The base plane of the house, in our reconstruction, consists of:

- The ground plane (the geological plane).
- The "floor" plane, that includes all those elements meant to sustain the rest of the house.

The ground plane shows no signs of preparation for the house construction. According with our theory, the floor plane consisted of several short forks, a framing and the actual floor. The short forks were inserted directly into the ground plane. These forks were meant to space apart the ground plane from the house, preventing water and moisture from penetrating the structure. The ground plane and the house are spaced 30 cm apart. These forks also worked as support for the framing, made of crisscrossed elements (logs, branches and planks) acting as joists, and supporting the actual floor. The floor seems to have been composed of both long branches and planks, some of which had a triangular section (having been obtained cutting a log into "wedges"). Potential gaps between these elements were probably closed with smaller branches or/and other wooden elements. Regarding its dimensions, we hypothesize that the base plane had and height of 1.37 m, a length of 6.27 m and a width of 3.50 as described in chapter 4.1.

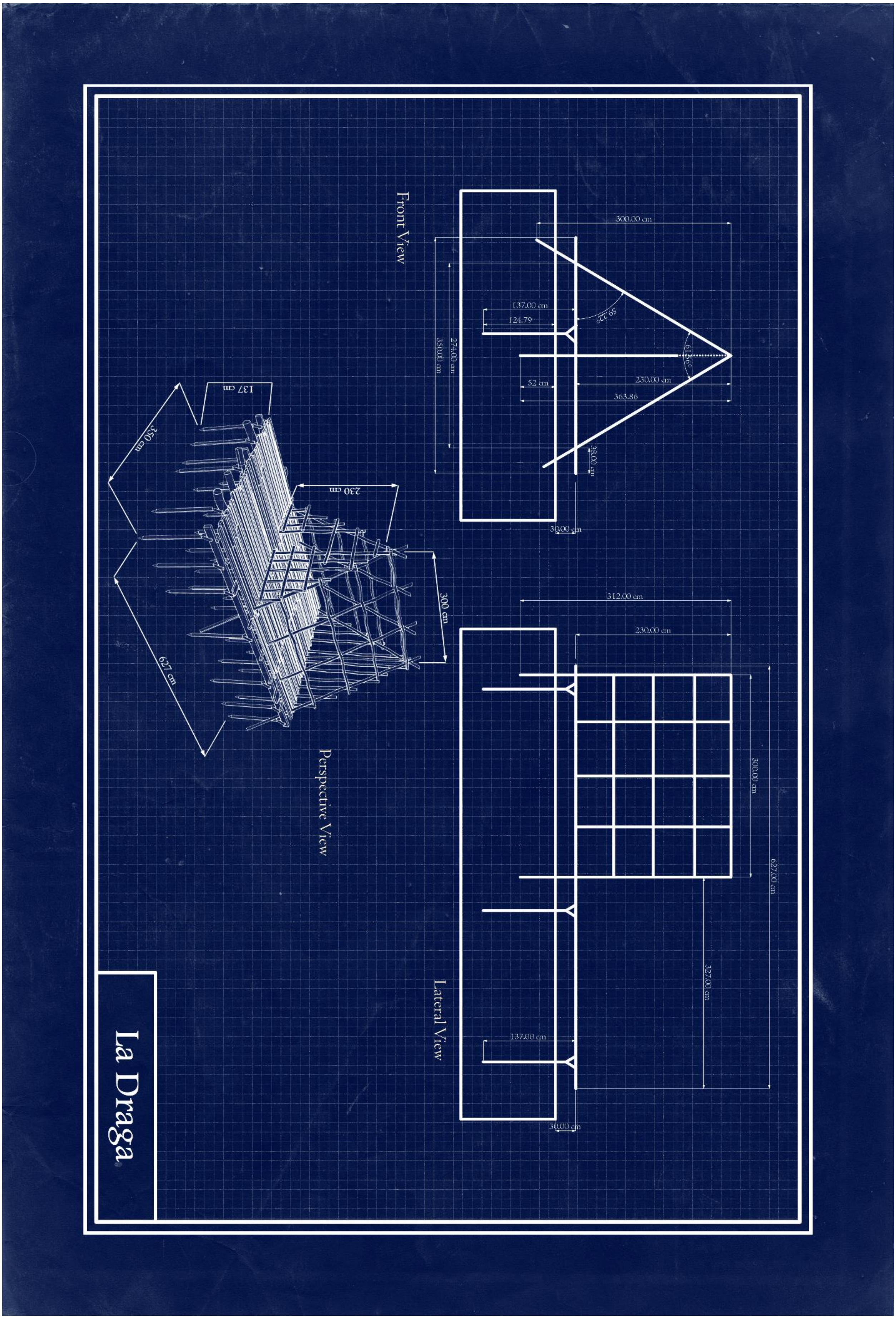
At La Draga, the overhead plane of the houses corresponded (in our hypothesis) with the roof plane. We assumed that the overhead plane structure included a horizontal ridge beam supported, at least, by two main vertical long forks;

several tilted elements plunged into the soil and acting as rafters of which at least four acting as principal ones; several horizontal elements acting as purlins and connected with the tilted elements creating a criss-crossed frame. This assemblage create the peculiar form known in architecture as A-Frame house. In our reconstruction, the overhead plane was 3.12 m high, 3 m long and, at the intersection point with the base plane, 2.74 wide. The tilted elements composing the latera walls/roof pitches had a slope degree between 60º and 55º. The overhead plane also defined the dimension of the house interior. We assume that the interior space of the house was 2.30 m high, 2.74 m wide and 3 m long, as described in chapter 4.2.

The vertical plane instead, was probably composed of two vertical walls made of crisscrossed wooden elements (like piles and branches) arranged in two frames (one on the front, one on the back). The vertical elements of the frames rested on the base plane while the horizontal elements were probably just tied to them. The resulting frames leaned against the main rafters of the overhead plan, probably tied using lianas and/or ropes. On the frontal wall there was probably the door that lead to the house interior. The wall frame was probably rectangular and closed by a piece of leather. The presence at La Draga of elements composed of oak branches intertwined seems to suggest that the wall sheathing was made of these elements. Seems probably that there were no windows: in case of necessity, holes can be easily obtained piercing the walls. We estimated that the vertical plane had a high of 2.30 m and a width of 2.74 m as explained in chapter 4.3.

Finally, we assumed the presence of a working area on the platform directly in front of the house: in our reconstruction the rear wall of the house was perpendicularly aligned with the rear side of the base plane. Since the base plane was 6.27 m long and the house interior was 3 m long, the frontal working area would measures c. 3.27 m, as described in chapter 4.2.

In our research we were able to describe and analyse the Neolithic house using the analytical categories coming from modern architecture and using a specific and standardized language meaning that we were able to define both the planes (base plane, vertical plane, overhead plane) characterizing the cabins of La Draga and the element composing them (rafters, purlins etc.). Moreover, we were able to create a generic descriptive model to describe the general function of these elements: is an element mono-functional or multi-functional? It is homogeneous or heterogeneous? It is natural or artificial? Our intention was to use both these categories and this terminology to set a standard procedure and vocabulary to use to analyse, describe and reconstruct any prehistoric architecture, since this essential aspect is still quite missing in archaeology especially prehistoric archaeology.


La Draga
Front View
Lateral View
Perspective View
300.00 cm
137.00 cm
124.79
274.00 cm
350.00 cm
52 cm
230.00 cm
363.86
38.00 cm
30.00 cm
312.00 cm
300.00 cm
627.00 cm
327.00 cm
137 cm
350 cm
230 cm
300 cm
627 cm

The other main goal achieved in this investigation, and that has gone beyond all expectations, has be the development of a BIM (Building Information Module) process. Usually the BIM process is used to manage the information about a standing structure, to describe its characteristics, its needs and the information about it. BIM models are made up of intelligent objects that when changed stay updated throughout the design no matter who is working with it. The key word in BIM is “Information”. BIM is centred on models made up of objects. Moreover, unlike 2D CAD, in which a user describes a real-world three-dimensional object with multiple 2D drawings, with BIM the user directly constructs a 3D digital model, and from this model produces 2D projections by way of description.

We start with the idea of creating a BIM process to handle and display both the archaeological data, both the reconstructive hypothesis about the lost elements of the houses of La Draga. However, during the design phase, we soon realized that we could go beyond, that we could create a BIM process not only for our specific case but also for all the archaeological sites in general. We have been able to design a procedure (currently in alpha test) to build a parametric and informed 3D model of an archaeological structure. Following the architectonical definitions we used for our site, we were able to define general groups, families and objects capable of handle any situation. The structure are divided on the base of the architectonic planes (base plane, vertical plane and overhead plane) each of which has his families and objects. We created a library of object but, because we know that each site is different from the other, new elements can be also easily added. Moreover, families allow connecting elements meaning that if I change a value all the connected elements change their values as one. This is a very important aspect because especially in the reconstructive phase because one can easily see how a hypothesis would affect the rest of the structure.

Other important aspect is that, being an open process, each time I have a new data I can add it and be able to see how the rest of the model react to the new information. I can also link all the information I have about a specific object (photos, diagrams etc.) and I can easily recall them whenever I want.

Moreover, I can run physical stress test on a single object or on the entire model, or undertake tests about the lightening of the interior of the heat dispersal patterns.

6.1 THE “*THREE LITTLE PIGS*” THEORY

The last outcome of this research is the development of what I have called “*The three little pigs theory*”. This theory describes how buildings having similar shapes, dimension etc. may not only have very different meanings and functions but also different resistances, responses a same kind of physic force.

In the story, the three brother pigs built three houses made of, respectively, straw, wood and stone. When the wolf come to catch the three brothers, he succeed to destroy the first two houses just blowing them away, but failing against the third because more solid. Beyond the moralistic, anthropological and sociological meanings of this tale, the “materialistic aspect” of the story shows how the houses of the three pigs even if similar in shape, being made of different material have different resistance against the wolf’s breathe.

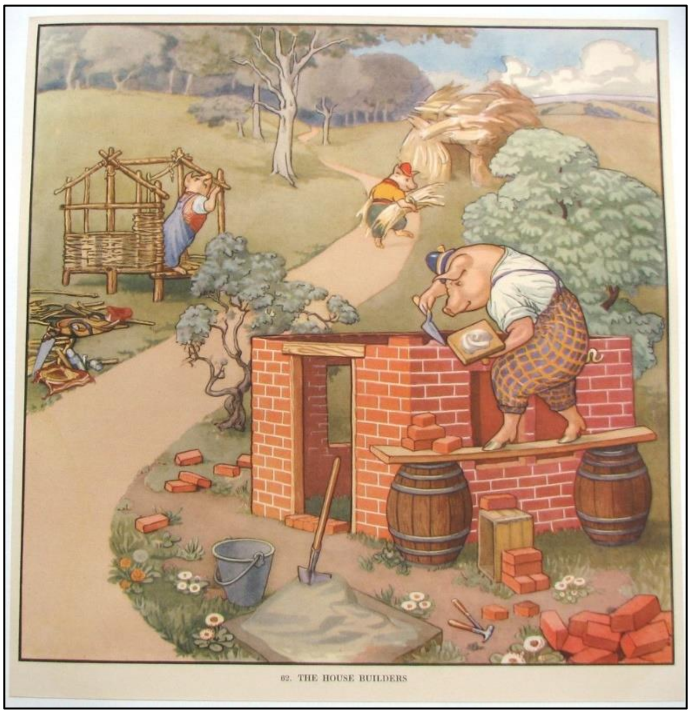


Fig.184: 1930's British “Three Little Pigs” Fairy Tale Vintage Children's Poster (www.pinterest.com).

In physical terms, this means that the three different materials (straw, wood, stone) have different proprieties, therefore a different resistance against an external physic force (in this case the wolf's breath) and thus also the three structures. That is exactly wat happen in reality. I developed this theory to demonstrate why is not possible to infer social similitudes (e.g. the number of people living inside a house) between Neolithic pile dwellings and other Neolithic houses starting from, or just on the base of, similarities in dimensions. As I said, different materials have different physical and mechanical proprieties. If I built a table made of wood and a table made of iron and then apply to them the same *x* Newtonian force (or a force of any kind) the reaction will be different, as shown in figure 185.

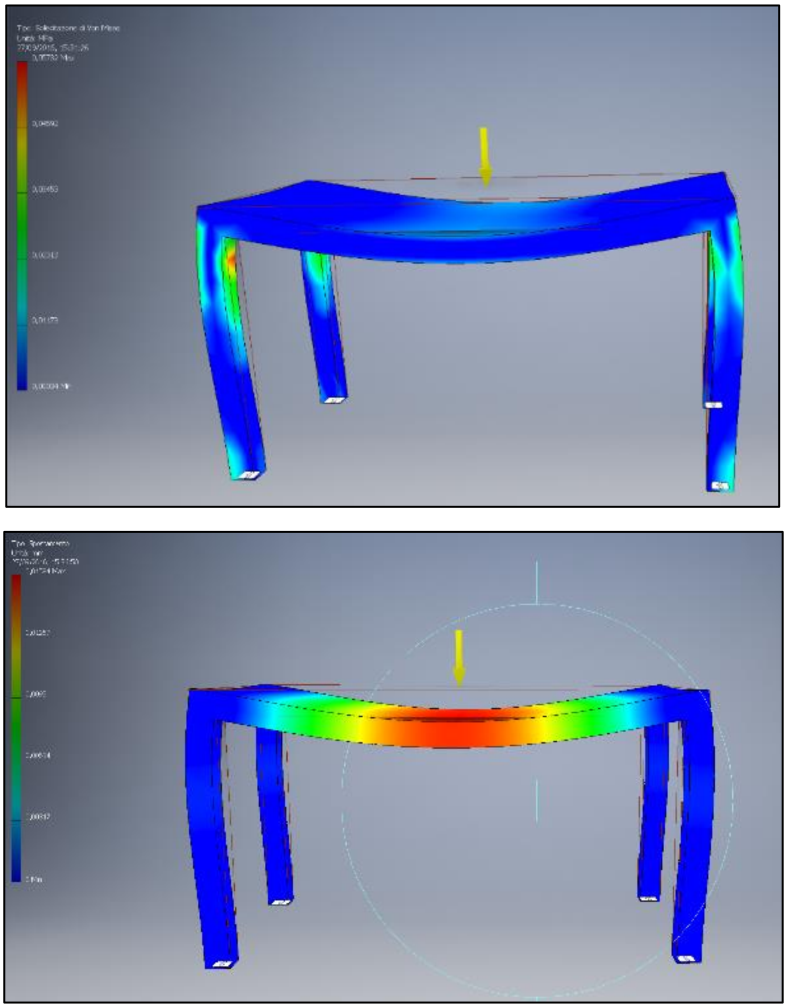


Fig.185: Due to their different characteristic two different elements will respond in a different way to the same force: on the top an iron table, on the bottom a wooden table (image by the author).

The same applies to the houses: if I construct two identical houses, one made of wood and the other made of iron, they will have different physical/mechanical properties and different reactions to a same external physical force.

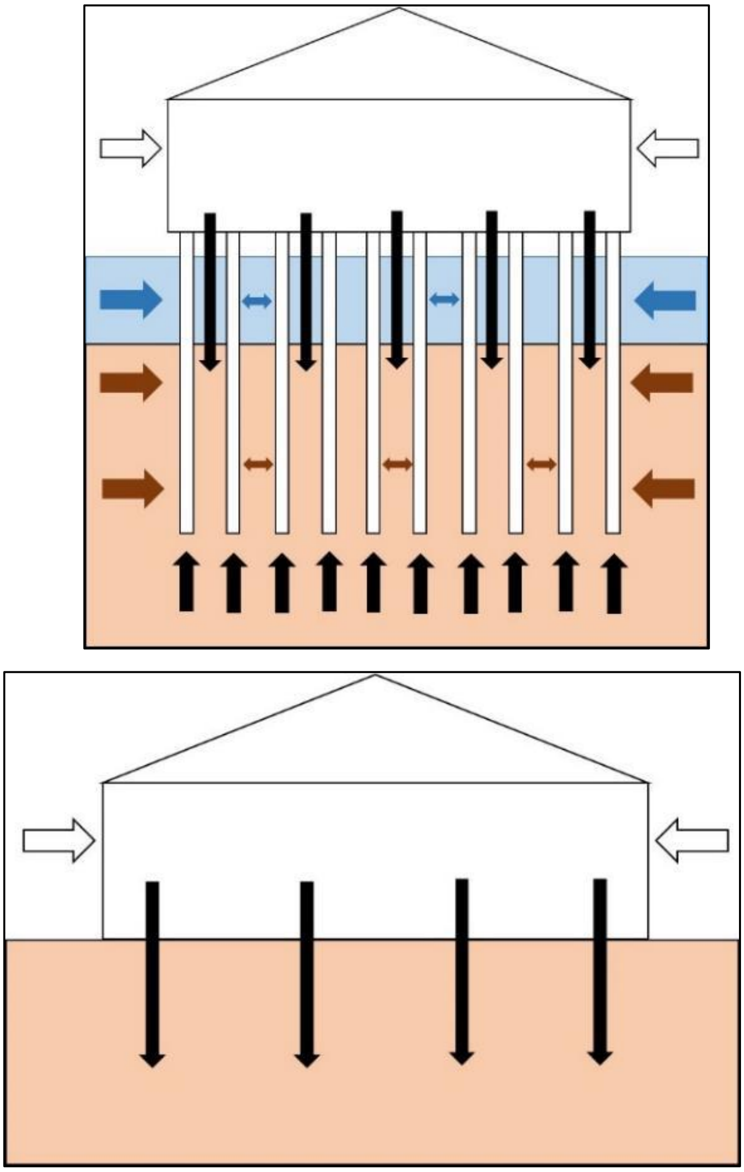
To this notion, we have to add another element: the physic characteristics of the surrounding environment where the structure is built. As for the building materials, also different soils have different proprieties: a stone layer has characteristic very different from a clay layer meaning that, for examples, the forces that they are capable to hold are very different.

Moreover, the relation between house structure and soil is different: even if a pile dwelling and another type of Neolithic house share the same perimeter dimensions and even the same type of soil, the relation between this and the houses base planes is completely different (not to mention if the soil is different). In the first case the base plane, that held the entire house, consists of a structure made of vertical piles inserted into the water and into the underlying soil, while in the second case the base plane is the soil itself or it is just lying on it.

This means that the forces in actions are different and of different intensity (Fig.186). The forces acting on a pile dwelling (chapter 2.9) are greater and different from those acting on a "normal" house. Among these, the most prominent are the vertical load and the soil resistance that are strictly connected since each different soil has a different carrying capacity: a soil made of, for example, wet clay is much more instable than a soil made of rock or dry clay. This means that the houses weight cannot exceed the soil resistance to be "safe". If the weight is excessive, the house will start to bend, crack or sink.

A house built on a solid ground usually does not has "less" problems and can hold a heavier load.

Thus, if we have a pile dwelling and a stone house both having a perimeter of 4x4 m the number of occupant will be different: the stone house, being built on a more reliable type of soil can host a higher number of people of materials, the only limitations are the walls and the roof. On the contrary, the pile dwelling can support only a limited number of people or/and materials that has to be equal or inferior to the soil carrying capacity. The moment the vertical load, that is the weight of the house plus the weight of the occupants and the materials, overcome the carrying capacity of the soil or of the piles, the house start to collapse or to sink.



186

Fig.186: The different forces that act on a pile dwelling (top) and a house built directly on the ground (images by the author).

This theory demonstrates how, making similitudes among different type of structures based just on similarity in shapes or dimensions can be an impossible or at least a tricky task.

7 ANNEX

7.1. RHINOCEROS 5

The reconstructive process has been made using Rhinoceros 5 (https://www.rhino3d.com/es/). We chose this program because it is a very good mid-point between CAD programs and complex 3D modelling programs like 3DSM or Maya and it has a gentler learning curve. In essence, Rhino is a very flexible and user-friendly 3D surface-modelling tool, enabling to construct NURBS (Non-uniform rational basis spline) surfaces as well as polygonal meshes for making 3D models of free-form objects. To facilitate NURBS surface construction, it provides a comprehensive set of tools for making and manipulating NURBS curves and point objects. Constructing the model of an object usually concerns the making of two or more surfaces with different surface patterns. For easy handling of surface objects, you may join two or more contiguous surfaces sharing common edges to form a polysurface. Among the many ways to represent a solid in the computer, Rhino's solid is a surface or a polysurface enclosing a volume without any gaps, openings, or intersections among the individual surfaces. To obtain special form and shape effects from surfaces that are already constructed, one can use Rhino's transformation tools. To help improvise the design, Rhino provides a set of analysis tools. To facilitate the management of models of products or systems with a number of components, Rhino enables to construct block definition and block instances. To cope with other upstream and downstream-computerized operation, Rhino enables to import and export various file formats. To facilitate human interpretation of design, Rhino enables to output 2D engineering drawing. In terms of rendering and animation, one can use Rhino's basic rendering tool as well as other plug-in tools, such as Flamingo and Bongo. In essence, the purpose of constructing a computer model of an object is to represent it in the computer in digital form in order to facilitate design, analysis, and downstream processes in particular computerized operations.

NURBS
Non-uniform rational basis spline (NURBS) is a mathematical model commonly used in computer graphics for generating and representing curves and surfaces. It offers great flexibility and precision for handling both analytic (surfaces defined by common mathematical formulae) and modeled shapes. NURBS are commonly used in computer-aided design (CAD), manufacturing (CAM), and engineering (CAE) and are part of numerous industry wide standards, such as IGES, STEP, ACIS, and PHIGS. NURBS tools are also found in various 3D modeling and animation software packages .
They can be efficiently handled by the computer programs and yet allow for easy human interaction. NURBS surfaces are functions of two parameters mapping to a surface in three-dimensional space. The shape of the surface is determined by control points. NURBS surfaces can represent, in a compact form, simple geometrical shapes. T-splines and subdivision surfaces are more suitable for complex organic shapes because they reduce the number of control points twofold in comparison with the NURBS surfaces.
In general, editing NURBS curves and surfaces is highly intuitive and predictable. Control points are always either connected directly to the curve/surface, or act as if they were connected by a rubber band. Depending on the type of user interface, editing can be realized via an element's control points, which are most obvious and common for Bézier curves, or via higher level tools such as spline modeling or hierarchical editing (https://wiki.mcneel.com/rhino/nurbs; http://en.wikipedia.org/wiki/NURBS)

Using computer-aided design and rendering applications, is it possible to represent the object's geometry, texture, and colour. To make better use of the computer and computer-aided design applications, one need to know the various ways models are represented in the computer, the types of modelling tools available, and the techniques for using these tools. Basically, is possible to represent a 3D object in the computer in three ways: as a wireframe model, as a surface model, or as a solid model:

Wireframe model

In the history of computer modelling, the 3D wireframe model is the earliest type of 3D model. It is the most primitive type of 3D object. In essence, a wireframe model is a set of un-associated curves assembled in 3D space. The curves serve only to give the pattern of a 3D object. There is no relationship between the curves. Therefore, the model does not have any surface information or volume information. It has only data that describe the edges of the 3D object. Because of the limited information provided by the model, the use of wireframe models is very confined.

Surface model

In the computer, a surface is a mathematical construct represented as a thin sheet without thickness. A surface model is a set of contiguous surfaces assembled in 3D space to represent a 3D object. When compared to a 3D wireframe model, a surface model has, in addition to edge data, information on the contour and silhouette of the 3D object. Surface models are typically used in computerized manufacturing systems and in the generation of photorealistic rendering or animation.

Solid model

Concerning information, a 3D solid model is superior to the other two models because a solid model in a computer is a complete representation of the object. It integrates mathematical data that includes surface and edge data as well as data on the volume of the object the model describes. In addition to visualization and manufacturing, solid modelling data is used in design calculation.

7.2. OTHER PROGRAMS

Even if Rhino 5 was the final platform chosen to undertake this research, during these last three years we explored other programs.

7.2.1. SketchUp

SketchUp, formerly Google SketchUp, is a 3D modeling computer program for a wide range of drawing applications such as architectural, interior design, landscape architecture, civil and mechanical engineering, film and video game design. In SketchUp, everything is made up of one of two kinds of things: edges and faces. Edges are lines, they are always straight and they do not have thickness. Faces are surfaces and they cannot exists without edges. To have a face, you need to have at least three coplanar (on the same plane) edges that form a loop. In other words, a face is defined by the edges that surround it, and those edges all have to be on the same, flat plane. Faces are always flat and, like the edges, they do not have thickness. They are the basic building blocks of every model you will ever make.

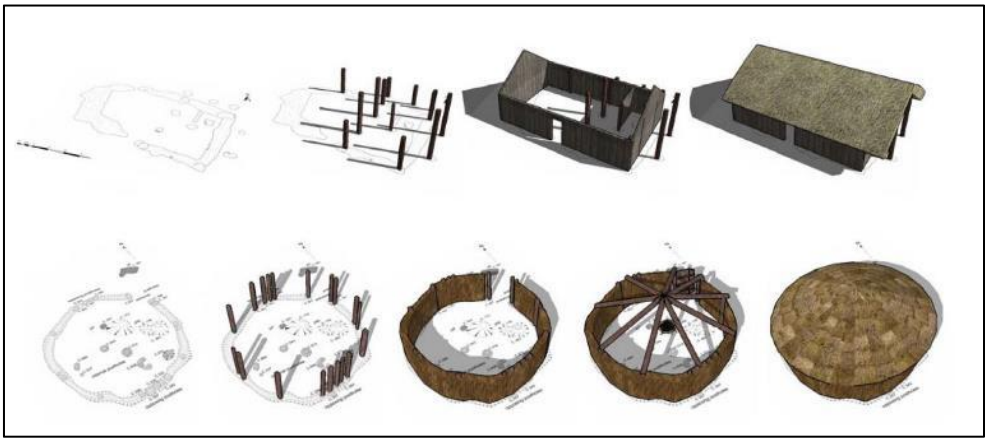


Fig.187. Top: the stages of construction for the rectangular house at Ballinglanna. **Bottom**: the stages in construction for the roundhouse at Mackney. Both the reconstruction were made using SketchUp (http://www.surveyingarchaeology.co.uk).

7.2.3. 3D Studio Max

Autodesk 3ds Max, formerly 3D Studio, then 3D Studio Max is a professional 3D computer graphics program for making 3D animations, models, games and images. It is developed and produced by Autodesk Media and Entertainment. It has modelling capabilities and a flexible plugin architecture and can be used on the Microsoft Windows platform. Video game developers, many TV commercial studios and architectural visualization studios frequently use it. It is also used for movie effects and movie pre-visualization. For its modelling and animation tools, the latest version of 3ds Max also features shaders (such as ambient occlusion and subsurface scattering), dynamic simulation, particle systems, radiosity, normal map creation and rendering, global illumination, a customizable user interface, new icons, and its own scripting language.

7.2.4. SolidWorks

The SOLIDWORKS® CAD software is a mechanical design automation application that lets designers quickly sketch out ideas, experiment with features and dimensions, and produce models and detailed drawing.

Parts are the basic building blocks in the SOLIDWORKS software. Assemblies contain parts or other assemblies, called subassemblies. A SOLIDWORKS model consists of 3D geometry that defines its edges, faces, and surfaces. The SOLIDWORKS software lets you design models quickly and precisely.

SOLIDWORKS models are:

- Defined by 3D design
- Based on components

SOLIDWORKS uses a 3D design approach. As you design a part, from the initial sketch to the final result, you create a 3D model. From this model, you can create 2D drawings or mate components consisting of parts or subassemblies to create 3D assemblies. You can also create 2D drawings of 3D assemblies. When designing a model using SOLIDWORKS, you can visualize it in three dimensions, the way the model exists once it is manufactured. One of the most powerful features in the SOLIDWORKS application is that any change you make to a part is reflected in all associated drawings or assemblies

7.2.5. Blender

Blender is a professional free and open-source 3D computer graphics software product used for creating animated films, visual effects, art, 3D printed models, interactive 3D applications and video games.

Fig.188: A dolmen created using Blender (model by the author).

Blender's features include 3D modelling, UV unwrapping, texturing, raster graphics editing, rigging and skinning, fluid and smoke simulation, particle simulation, soft body simulation, sculpting, animating, match moving, camera tracking, rendering, video editing and compositing. It further features an integrated game engine.

7.2.6. Grasshopper

Grasshopper is a visual programming language and environment developed by David Rutten at Robert McNeel & Associates that runs within the Rhinoceros 3D computer-aided design (CAD) application. Programs are created by dragging components onto a canvas. The outputs to these components are then connected to the inputs of subsequent components. Grasshopper is primarily used to build generative algorithms, such as for generative art. Many of Grasshopper's components create 3D geometry. Programs may also contain other types of algorithms including numeric, textual, audio-visual and haptic applications. Advanced uses of Grasshopper include parametric modelling for structural engineering, parametric modelling for architecture and fabrication, computational Japanese garden design, lighting performance analysis for eco-friendly architecture and building energy consumption.

REFERENCES

A

Abebe, A. and Smith, I. G. 2005. Pile Foundation Design: A Student Guide. *Pile Foundation Design*. (www.tumcivil.com).

Adejumo, T. W. 2013. Installation techniques of pile foundation on some low bearing capacity soils in Nigeria. *African Journal of Engineering Research,* 1(2): 17-22.

Aish, R. 1986. Building Modelling: the key to integrated construction CAD. In *CIB 5th International Symposium on the Use of Computers for Environmental Engineering Related to Buildings,* 5:7-9.

Altorfer, K. 1999. Neue Erkenntnisse zum neolithischen Türflügel von Wetzikon ZH-Robenhausen. *Zeitschrift für schweizerische Archäologie und Kunstgeschichte*, 56(4):217-230.

Amt für Archäologie Thurgau (2010) *Archäologie im Thurgau*, Frauenfeld: Huber.

Anderson, K. M. 1969. Ethnographic analogy and archeological interpretation. *Science* 163:133–138.

Antolín, F. and Buxó, R. 2011. L'explotació de les plantes: contribucióa la història de l'agricultura i de l'alimentació vegetal del Neolític a Catalunya a Bosch, A., Chinchilla, J. i Tarrús, J. (Eds.), *El poblat lacustre del Neolític antic de la Draga. Excavacions 2000–2005*. Girona: CASC – Museu d'Arqueologia de Catalunya (Monografies del CASC, 9), 147-174.

Antolín, F. 2013. *Of cereals, poppy, acorns and hazelnuts. Plant economy* *among early farmers (5400–2300 cal BC) in the NE of the Iberian Peninsula. An archaeobotanical approach*. Universitat Autònoma de Barcelona, Barcelona.

Argilagós, J.B., Vericat, T.F. and Prades, M.D.M.V. 1996. El" Barranc d'en Fabra": asentamiento de inicios del IV milenio aC en el curso inferior del Ebro. Rubricatum: *revista del Museu de Gavà*, 1:391-396.

Armit, I. 1996. *The Archaeology of Skye and the Western Isles*. Edinburgh, Edinburgh University Press.

Arnold, B. 1990. Cortaillod-Est et les villages du lac de Neuchâtel au Bronze final. Structure de l'habitat et proto-urbanisme. *Archéologie Neuchâteloise*, 6.

Arnoldussen, S. 2007. *A living landscape: Bronze Age settlement sites in the Dutch river area* (c. 2000-800 BC). Sidestone Press.

Artaud, A. 1958. *The theater and its double* (Vol. 127). Grove Press.

Artursson, M., T. Linderoth, M.-L. Nilsson and M. Svensson. 2003. Byggnadskultur i södra och mellersta Skandinavien. In *I det neolitiska rummet*, ed. M. Svensson, 40–171. Stockholm: Riksantikvarieämbetet.

Ascalew, A. and Ian Smith, G. N. 2007. Pile foundation design: A student guide. *School of the Built Environment, Napier University, Edinburgh. Balkema/Rotterdam/Boston*, pp. 83-102.

Ascher, R. 1961. Analogy in archaeological interpretation. *Southwestern Journal of Anthropology*, 17:317–325.

Ask, C. 2012. Interpreting in 3D. *Master's thesis, Lund University, Sweden*.

Atiénzar, G. G., López, F. 2008. El yacimiento de Fuente de Isso y el poblamiento neolítico en el Campo de Hellín (Albacete). In *Actas del IV Congreso del Neolítico Peninsular* 1: 117-125.

B

Baker, D. 2012. Defining Paradata in Heritage Visualization. In: *Paradata and Transparency in Virtual Heritage*, pp. 163-175.

Bakker, G., Meulenberg, F. and Rode, J. D. 2003. Truth and credibility as a double ambition: reconstruction of the built past, experiences and dilemmas. *Computer Animation and Virtual Worlds*, 14(3):159-167.

Balachandran, M., Gero, J.S. 1990. Role of prototypes in integrated expert systems and CAD systems. In *Applications of Artificial Intelligence in Engineering*. V. Gero, J.S. (Ed.), Springer-Verlag, Berlin, 1:195-211.

Baldassari, G. L., Demetrescu, E., Pescarin, S., Eriksson, J. and Graf, H. 2013. Behind Livia's Villa: A Case Study for the Devolution of Large Scale Interactive" in-site" to" on-line" Application. In *International Conference of Design, User Experience, and Usability* (pp.238-247). Springer, Berlin, Heidelberg.

Baldo, B. 1989. *La palafitta di Ledro: primo scavo effettuato nel 1929 dalla sovrintendenza alle antichità della tre Venezie diretto dal prof. Ettore Ghislanzoni*. In I quattro Vicariati e le zone limitrofe (66), Rivista semestrale di cultura e vita, Ala, pp.31-35

Bánffy, E. 2000. The late Starčevo and the earliest Linear Pottery groups in Western Transdanubia. *Documenta Praehistorica*, 27:173–185

Bánffy, E. 2004. *The 6th Millennium BC Boundary in Western Transdanubia and its Role in the Central European Neolithic Transition. (The Szentgyörgyvölgy-Pityerdomb Settlement)*. Budapest: Archaeological Institute of the Hungarian Academy of Sciences.

Bánffy, E. 2005. Mesolithic-Neolithic contacts as reflected in ritual finds. *Documenta Praehistorica*, 32: 73-86.

Bánffy, E. and Oross, K. 2010. The earliest and earlier phase of the LBK in Transdanubia. In D. Gronenborn and J. Petrasch (Eds.) *Die Neolithisierung Mitteleuropas. Internationale Tagung*, *Mainz 24. bis 26. Juni* 2005. Mainz: Verlag des RGZM, pp. 255–272.

Banning, E. B. and B. F. Byrd. 1987. Houses and the changing residential unit: Domestic architecture at PPNB 'Ain Ghazal, Jordan. *Proceedings of the Prehistoric Society* 53:309–325.

Barceló, J. A. 2001. Virtual Reality and Scientific Visualization: Working with Models and Hypotheses. *International Journal of Modern Physics C*, 12(04), 569-580.

Barceló, J.A., Forte, M. and Sanders, D.H. (Eds.) 2000. Virtual Reality in Archaeology, Oxford, BAR International Series 843.

Barceló, J. A., and Moitinho, V. M. 2012. Functional analysis from visual and non-visual data. an artificial intelligence approach. *Mediterranean Archaeology and Archaeometry*, 12(2):273-321.

Barceló, J. A., 2014. 3D Modeling and Shape Analysis in Archaeology. In Remondino, F., Campana, S., 2014: *3D Recording and Modelling in Archaeology and Cultural Heritage - Theory and Best Practices. Archaeopress* BAR Publication Series 2598, 9:15-23.

Bar-Yosef, O. 1981. From hunter to herder in southern Sinai. In *Temples and high places in Biblical times*, (Eds.). A. Biran and I. Pommerantz, 156–157.

Jerusalem: Hebrew Union College.

Bar-Yosef, O. and A. Gopher, (Eds.). 1997. *An early Neolithic village in the Jordan valley. Part I: The archaeology of Netiv Hagdud*. Cambridge: Harvard University.

Bar-Yosef, O., A. N. Goring-Morris and A. Gopher, (Eds.). 2010. "*Gilgal: excavations at early Neolithic sites in the lower Jordan valley. The excavations of Tamar Noy"*. Oakville: ASPR Monograph Series & Oxbow.
Battjes J.A. 2002. *Vloeistofmechanica*, Tu Delft.

Barrasetas, E. 1994. Les restes d'època romana i de l'antiguitat tardana del jaciment de la Bòbila Madurell. *Arraona: revista d'història*, (15):63-70.

Baerreis, D.A. 1961. The ethnohistoric approach and archaeology. *Ethnohistory,* 8:49–77.

Battaglia, R. 1943. *La palafitta del Lago di Ledro nel Trentino*. Tipografia editrice mutilati e invalidi.

Baudrillard, J. 1981. Simulacra and Simulation. Paris: Editions Galilee. *Baudrillard Simulacres et Simulation 1981*.

Beacham, R., Denard, H. and Niccolucci, F. 2006. An introduction to the London charter. *Joint Event CIPA/VAST/EG/EuroMed*.

Becker, K., Cooney, G., Coles, J., Ryan, M., & Sievers, S. (Eds.). 2009. *Relics of Old Decency: Archaeological Studies in Later Prehistory*: *Festschrift for Barry Raftery*. Wordwell.

Beneša, J., Vondrovskýa, V., Kovačikováa, L., Šídab, P. and Divišováa, M. 2014. Decoding the Neolithic Building Complex: the Case of the Extraordinarily

Large House III from Hrdlovka, Czech Republic. *Interdisciplinaria Archaeologica: Natural Sciences in Archaeology*, 5:99-118.

Benjamin, W. (1935). 2010. “The Work of Art in the Age of Its Technological Reproducibility (First Version),” translated by Michael W. Jennings. *Grey Room*, *39*:11-37.

Bernardes, P., Magalhães, F., Ribeiro, J., Madeira, J. and Martins, M. 2014. Image-based 3D modelling in archaeology: application and evaluation. In *22nd International Conference in Central Europe on Computer Graphics, Visualization and Computer Vision*, pp. 159-166. Vaclav Skala–Union Agency.

Betts, A. (Eds.). 1998. *The Harra and the Hamad. Excavations and surveys in eastern Jordan, Volume 1*. Sheffield, Sheffield Archaeological Monographs, 9.

Bettinger, R.L., Boyd, R. and Richerson, P.J. 1996. Style, Function, and Cultural Evolutionary Processes. In *Darwinian Archaeologies*. Maschner HDG (Ed.), Plenum Press, New York, pp.133-164.

Bianchin Citton, E. and Martinelli, N. 2005. Cronologia relativa e assoluta di alcuni contesti veneti delletà del bronzo Recente, Finale e degli inizi delletà del Ferro. Nota Preliminare. *Bartoloni G., Delpino F.(Eds.), Oriente e Occidente: metodi e discipline a confronto. Riflessioni sulla cronologia delletà del Ferro italiana, Pisa-Roma*, 239-254.

Bicici, E., St. Amant, R. 2003. *Reasoning about the Functionality of Tools and Physical Artefacts*. Technical Report TR-2003-22. Department of Computer Science, North Carolina State University.

Bijen, J. 2003. *Durability of engineering structures: Design, repair and maintenance*. Elsevier.

Bilbija, M. 1986. Cerje, neolitsko naselje. *Arheološki Pregled,* 1985:35–36.

Billamboz, A. and Gollnisch, H. 1998. Die Dendrodatierung der Siedlungsphasen von Uerschhausen-Horn (CH Thurgau) in der Spätbronzezeit und frühen Eisenzeit. *Platform*, *5*, 102-103.

Binford, L.R. 1967. Smudge pits and hide smoking: The use of analogy in archaeological reasoning. *American Antiquity*, 32:1–12.

Binford, L.R. 1968. Methodological considerations of the archaeological use of ethnographic data. In Lee, R. B., and DeVore, I. (Eds.), *Man the Hunter, Aldine*, Chicago, pp. 268–273.

Binford, L.R. 1972. Archaeological reasoning and smudge pits—revisited. In Binford, L.R. (Ed.), *An Archeological Perspective*, Seminar Press, New York, pp. 52–58.

Binford, L.R. 1978a. Dimensional analysis of behaviour and site structure: learning from an Eskimo hunting stand. American Antiquity, 43(3), 330-361.

Binford, L.R. 1978b. *Nunamiut Ethnoarchaeology*. New York: Academic Press.

Binford, L.R. 1989. Styles of style. *Journal of Anthropological Archaeology*, 8:51-67.

Binford, L.R. 1991. "When the Going Gets Tough, the Tough get Going: Nunamiut Local Groups, Camping Patterns and Economic Organisation." In *Ethnoarchaeological Approaches to Mobile Campsites: Hunter-Gatherer and Pastoralist Case Studies*, edited by Clive Gamble, 25–137. Ann Arbor: International Monographs on Prehistory, Ethnoarchaeological Series 1.

Binford, S.R. 1968. Ethnographic data and understanding the Pleistocene. In Lee, R. B., and DeVore, I. (Eds.), *Man the Hunter, Aldine*, Chicago, pp. 274–275.

Birx, H.J. 2006. *Encyclopaedia of anthropology*. Sage publications.

Blaise, J.-Y. and Dudek, I., 2009. *3D as a Content, 3D as a Metaphor*. http://halshs.archives-ouvertes.fr/halshs-00474302.

Blanton, R.E. 1994 .*Houses and Households, a Comparative Study*. Plenum Press, New York

Bloomer, W. 1994. "From X-ray pictures to implants". *CAENEWS*, 3:13-17.

Bollnow, O.F., 1961. Lived-space. *Philosophy Today*, 5(1):31-39.

Bollnow, O.F. 1963. *Mensch und raum*. Kohlhammer.

Bollnow, O.F. 2011. *Human space*. London, Hyphen.

Bonde, S., Maines, C., Mylonas, E. and Flanders, J. 2009. *The virtual monastery: representing time, human movement, and uncertainty at Saint-Jean-des-Vignes, Soissons*. Vis. Resour. 25 (4):363-377.

Bonnet, J.C. 1992. *Towards a Formal Representation of Device Functionality*. Report KSL, pp. 92-54. Stanford University Knowledge Systems Laboratory.

Borić, D. 2008. First households and ‘house societies’ in European prehistory. In *Prehistoric Europe: theory and practice*, ed. A. Jones, 109–142. Chichester: Wiley-Blackwell.

Borra, D. 2004. Sulla verità del modello 3D. un metodo per comunicare la validità dell'anastilosi virtuale. In: *Workshop E-ArCom04*. Ancona.

Bosch, A., Buxó, R., Chinchilla, J., Palomo, A., Piqué, R., Saña, M., Tarrús, J., Terradas, X. 2012. Dinàmica d'ocupació de l'entorn lacustre de Banyoles i del jaciment neolític de La Draga. *XI Jornades d'Arqueologia de les Comarques de Girona*.

Bosch, A., Chinchilla, J., Tarrús, J. 2011. El poblat lacustre neolític antic de La Draga. Excavacions 2000 a 2005. Girona: Museu d'Arqueologia de Catalunya: Centre d'Arqueologia Subaquàtica de Catalunya. (*Monografies del CASC; 9*).

Bosch, A., Chinchilla, J., Tarrús, J. 2006. Els objectes de fusta del poblat neolític de La Draga. Excavacions 1995-2005. Girona: Museu d'Arqueologia de Catalunya: Centre d'Arqueologia Subaquàtica de Catalunya. (*Monografies del CASC; 6*).

Bosch, A., Chinchilla, J., Tarrús, J. 2000. El poblat lacustre neolític de La Draga. Excavacions 1990 a 1998. Girona, Museu d'Arqueologia de Catalunya: Centre d'Arqueologia Subaquàtica de Catalunya. (*Monografies del CASC; 2*).

Bosch, A., Buxó, R., Palomo, A., Buch, M., Mateu, J., Tabernero, E. y Casadevall, J. 1999. El poblado de Plansallosa y la neolitización del valle del Llierca (Pre-Pirineo oriental). En J. Bernabeu, y T. Orozco (coord.) *Actes del II Congrés de Neolític de la Pernínsula Ibèric.* Saguntum Extra-2:329-335. València, Universitat de València.

Bosch, A., Buxó, R., Palomo, A., Buch, M., Mateu, J., Tabernero, E. y Casadevall, J. 1998. L'explotació del territorio dels primers agricultors-ramaders del l'alta Garrotxa, in *Publicacions eventuals d'arqueologia de la garrotxa*: vol 5. Spain, Museo comarcal de la Garrotxa (Catalonia).

Bouzakis, K. D., Pantermalis, D., Efstathiou, K., Varitis, E., Paradisiadis, G. and

Mavroudis, I. 2011. An investigation of ceramic forming method using reverse engineering techniques: the case of Oinochoai from Dion, Macedonia, Greece. *Journal of Archaeological Method and Theory*, *18*(2):111-124.

Bradley, R. 2000. *An archaeology of natural places*. London, Psychology Press.

Brantingham, P.J. 2007. An Unified evolutionary model of archaeological style and function based on the Price equation. *American Antiquity*, 72(3):395-416.

Braun, E. 1997. *Yiftah'el, salvage and rescue excavation at a prehistoric village in Lower Galilee, Israel*. Jerusalem: Israel Antiquities Authority.

Bregant, T. 1996, Starejša, srednja in mlajša kamena doba ter bakrena doba / Early, Middle and Late Stone Ages, Copper Age. – V / In: *Pozdravljeni, prednamci! Ljubljana od prazgodovine do srednjega veka / Ancestral encounters! Ljubljana from Prehistory to the Middle Ages*, 18–45, Ljubljana.

Bregant, T. 1975, Kolišče ob Maharskem prekopu pri Igu – raziskovanja 1973. in 1974. leta (Der Pfahlbau am Maharski-Kanal bei Ig – Forschungen aus den Jahren 1973 und 1974). *Poročilo o raziskovanju neolita in eneolita v Sloveniji* 4:7–114.

Bregant, T. 1974. Kolišče ob Maharskem prekopu pri Igu – raziskovanja leta 1972 (Der Pfahlbau am Maharski-Kanal bei Ig – Untersuchungen im Jahre 1972). *Poročilo o raziskovanju neolita in eneolita v Sloveniji* 3:39–68.

Brown, L.A. and Moore, E.G. 1971. *Perspectives on Urban Spatial Systems*. Clark University.

Brughmans, T., Keay, S. and Earl, G. 2015. Understanding inter-settlement visibility in Iron Age and Roman Southern Spain with exponential random graph models for visibility networks. *Journal of Archaeological Method and Theory*, 22(1), 58-143.

Brück, J. 1999. Ritual and rationality: some problems of interpretation. In *European Journal of Archaeology* 2.3:313-344.

Byrd, B. F. 1994. Public and private, domestic and corporate: the emergence of the southwest Asian village. *American Antiquity* 59:639–666.

Byrd, B. F. 2005a. *Early village life at Beidha, Jordan: Neolithic spatial organization and vernacular architecture.* Oxford: Oxford University Press.

Byrd, B. F. 2005b. Reassessing the emergence of village life in the Near East. *Journal of Archaeological Research* 13:231–290.

C

Cairns, G. 2008. Advocating an ambivalent approach to theorizing the built environment. Building Research & Information, 36(3):280–289.

Calori, L., Camporesi, C. and Pescarin, S. 2009. Virtual Rome: a FOSS approach to WEB3D. In *Proceedings of the 14th International Conference on 3D Web Technology*, pp. 177-180. ACM.

Calvano, M. and Guadagnoli, F. 2016. Ricostruzione 3D della città di Amatrice. Una operazione di 'Instant Modeling'. *DISEGNARECON*, *9*(17):7-1.

Calvano, M. and Sacco, M. 2016. Dalla Forma Al Bim. Progettare Con I Modelli Informati - From The Form To Bim. Designing With Informed Models. In 3D Modeling & Bim, Empler, T. (Eds.), pp. 362-374. Sapienza University of Rome.

Calvano, M. and Casale, A. 2017. Il modello integrato e la conservazione dell'immagine della città. In *17th CIRIAF National Congress*.

Cameron, F. and Kenderdine, S. 2010. Theorizing Digital Culture. A Critical Discourse. Cambridge, MA: MIT Press.

Campbell, D.A. 2006. Modeling Rules, *Architecture Week*, http://www. architectureweek.com/2006/1011/tools_1 - 1.html

Campbell, E. and Lane, A. 1989. Llangorse: a 10th century royal crannog in Wales. *Antiquity* 63: 675–81.

Carandini, A. 2000. Storie dalla terra. Manuale di scavo archeologico. Giulio Einaudi Editore

Carri, A. 2014. Gli scavi dell'Università degli Studi di Milano presso il sito dell'età del Bronzo del Lavagnone (Desenzano del Garda, BS). *LANX. Rivista della Scuola di Specializzazione in Archeologia-Università degli Studi di Milano*, 17:17-23.

Cavers, M. G. 2010. *Crannogs and Later Prehistoric Settlement in Western Scotland*. Oxford, Archaeopress.

Cavers, M. G. 2006. Late Bronze Age and Iron Age lake settlement in Scotland and Ireland: the development of the 'crannog' in the north and west. *Oxford Journal of Archaeology* 25.4: 389–412.

Cavers, M. G. 2007. The complexity of crannog taphonomy: old and new evidence. In J. Barber, C. Clarke, M. Cressey *et al*. (Eds), *Archaeology from the Wetlands: Recent Perspectives*: 243–52. Edinburgh, Society of Antiquaries of Scotland.

Cerrato, I., Pescarin, S. 2013. Reconstructing past landscapes for virtual museums. In: *Good Practice in Archaeological Diagnostics*, pp: 285-296.

Cessford, C. 2001. A New Dating for Çatalhöyük. *Antiquity* 75:717–725.

Cessford, C. 2005. Estimating the Neolithic Population of Çatalhöyük. In *Inhabiting Çatalhöyük: Reports from the 1995–1999 Seasons*, edited by Ian Hodder, pp. 323–326. McDonald Institute for Archaeological Research/British Institute of Archaeology at Ankara, Cambridge.

Chang, K. C. 1967. Major aspects of the interrelationship of archaeology and ethnology. *Current Anthropology*, 8: 227–243.

Charlton, T. H. 1981. Archaeology, ethnohistory, and ethnology: Interpretive interfaces. *Advances in Archaeological Method and Theory*, 4:129–176.

Chausidis, N. 2008. Otvorite na neolitskite žrtvenici od tipot 'Majka – Kukja'. *Macedoniae Acta Archaeologica* 18:75–92.

Chen, Y.-R., Ariffin, S. I., & Wang, M.-H. 2008. The Typological Rule System of Malay Houses in Peninsular Malaysia. *Journal of Asian Architecture and Building Engineering*, (254).

Chinchilla, J., Piqué, R., Buxó, R. and Palomo, A. 2013. *Memòria dels treballs arquwologics desenvolupats al javiment neolitic lacustre de La Draga i de les prospeccions al voltant de l'estany (Banyoles-Pla de l'Estany)*, Excavacions 2010-2012, Equip La Draga, Memòria inèdita, Departament de Cultura de la Generalitat de Catalunya.

Ching, F.D.K. 2014. *Architecture: Form, space, and order*. John Wiley & Sons Inc. Inc., Hoboken, New Jersey.

Clark, G. 1954. *Excavations at Star Carr: an early mesolithic site at Seamer* *near Scarborough, Yorkshire*. Cambridge University Press. Cambridge.

Clark, J. D. 1968. Studies of hunter–gatherers as an aid to the interpretation of prehistoric societies. In Lee, R. B., and DeVore, I. (Eds.), *Man the Hunter, Aldine*, Chicago, pp. 276–280.

Clark, T.J. 2010. The Fallacy of Reconstruction. In Forte, M. *Cyber-Archaeology. Archaeopress-BAR International Series, 2177.*

Coles, B. 2004a. The development of wetland archaeology in Britain. In Menotti F. (Ed.). *Living on the lake in prehistoric Europe: 150 years of lake-dwelling research*. pp. 98-114. Routledge. London.

Coles, B. 2004b. Steps towards the Heritage Management of Wetlands in Europe. *Journal of Wetland Archaeology* 4: 183-198.

Coles, J., Coles, B. 1996. Enlarging the past. *The contribution of wetland archaeology. Edinburgh. Society of Antiquaries of Scotland, Society of Antiquaries of Scotland Monograph 11.*

Colley, S, Todd, S. and Campling, N. 1988. 3D Computer graphics for archaeological data exploration: an example from Saxon, Southampton. *Journal of Archaeological Science*, 15:99–106.

Collins, B. 1993. From ruins to reality – the Dresden Frauenkirche. *Institute of Electrical and Electronics Engineers Computer Graphics and Applications*, 13–15.

Crone, B. A. 2007. 'From indirections find directions out': taphonomic problems at Loch Glashan crannog, Argyll. In J. Barber, C. Clarke, M. Cressey et al. (Eds.), *Archaeology from the Wetlands: Recent Perspectives*: 223–30. Edinburgh: Society of Antiquaries of Scotland.

Crone, B. A., Henderson, J. C. and Sands, R. J. S. 2001. Scottish crannogs: construction, conflation and collapse: problems of interpretation. In B. Raftery and J. Hickey (Eds.), *Recent Developments in Wetland Research*: 55–67. Dublin, University Monographs.

Coudart, A. 1998. *Architecture et société néolithique: l'unité et la variance de la maison danubienne*. Paris, Editions de la Maison des Sciences de l'Homme.

Crawford, H. 1982. Analogies, anomalies and research strategy. *Paléorient*, 8: 5–9.

Cummins, R. 1975. Functional Analysis. *Journal of Philosophy* 72(20):741-765.

Cummins, R. 2000. "How does it work?" vs. "What are the laws?" Two conceptions of psychological explanation. In *Explanation and Cognition*. F. Keil, R. Wilson (Eds.), MIT Press, pp.117-145.

Cummins, R. 2002. Neo-Teleology. In *Functions. New Essays in the Philosophy of Psychology and Biology*. A. Ariew, R. Cummins, M. Perlman (Eds.), Oxford University Press.

Czech, K. 1982. Bestandsaufnahme des Unterwasserkulturerbes in den Salzkammergutseen. 7. Bericht. *Fundberichte aus Osterreich Horn*, 21:7-17.

D

David, N. 1971. The Fulani compound and the archaeologist. *World archaeology*, 3(2):111-131.

David, N. 1972. On the life span of pottery, type frequencies, and archaeological inference. *American Antiquity*, 37(1):141-142.

David, N., & Hennig, H. 1972. The Ethnography of Pottery. New York: Addison-Wesley Modular Publications

David, N., & Kramer, C. 2001. *Ethnoarchaeology in action*. Cambridge University Press.

Deal, M. 2017. The role of the direct historical approach in North American ethnoarchaeology: a northern perspective. *Ethnoarchaeology*, 9(1):30-52.

De Capitani A., Deschler-Erb S., Leuzinger U., Marti-Grädel E. & Schibler J. 2002. *Die jungsteinzeitliche Seeufersiedlung Arbon Bleiche 3. Funde*. Archäologie im Thurgau 11. (Frauenfeld).

De Leon, M. P. and Zollikofer, C. P. E. 1994. "Computer-assisted reconstruction of fossil hominids". *Proceedings of Pacific Graphics '94/CADDM'94*, Beijing, pp.390-392.

De Marinis, R. C., Rapi, M., Ravazzi, C., Arpenti, E., Deaddis, M. and Perego, R. 2004. Lavagnone (Desenzano del Garda): new excavations and palaeoecology of a Bronze Age pile dwelling site in northern Italy. In *Wetland Economies and Societies. Proceeding of the International Conference in Zurich*, pp: 10-13.

Demetrescu, E. 2015. Archaeological stratigraphy as a formal language for virtual reconstruction. Theory and practice. *Journal of Archaeological Science*, 57:42-55.

Denard, H. 2013. Implementing best practice in cultural heritage visualisation: the London charter. In *Good Practice in Archaeological Diagnostics* (pp. 255-268). Springer International Publishing.

Dennett, D.C. 1987. *The Intentional Stance*. The MIT Press, Cambridge (MA).

Dennett, D.C. 1991. Cognitive Science as Reverse Engineering: Several Meanings of 'Top-Down' and 'Bottom-Up'. *Proceedings of the 9th International Congress of Logic, Methodology and Philosophy of Science*. D. Prawitz, B. Skyrms, D. Westerstahl (Eds.).

Deplazes, A. 2008. *Constructing Architecture: Materials-Processes-Structures. A Handbook.* Birkhäuser.

Doerr, M. 2003. The CIDOC conceptual reference module: an ontological approach to semantic interoperability of metadata. *AI magazine*, 24(3):75.

Dosedla, H. 2016. Right Things in their Right Place. Interior design and room management of Neolithic standards at Lake Federsee and Lake Kopiago. *Mitteilungen der Anthropologischen Gesellschaft* in Wien (MAGW) Band 146. S.

Drennan, M. E. 2010. Architecture in archaeology: an examination of domestic space in Bronze Age Mesopotamia. *Honors Scholar Theses*, 167.

Dudek, I. and Blaise, J.-Y. 2004. Graphic Variables for Dynamic 2D/3D Documentation Visualisation in the Context of Historical Architecture. In: *Archives & Museum Informatics*, vol. 2.

Dunn, S. and Woolford, K. 2013. Reconfiguring Experimental Archaeology Using 3D Movement Reconstruction. In *Electronic Visualisation in Arts and Culture*, pp. 277-291. Springer London.

Dunnell, R.C. 1978. Style and Function: A Fundamental Dichotomy. *American Antiquity*, 43(2):192-202.

Düring, B. S. 2007. *The Articulation of Houses at Neolithic Çatalhöyük, Turkey, in The Durable House: House Society Models in Archaeology,* edited by Robin A. Beck, Jr. Center for Archaeological Investigations, Occasional Paper No. 35. © 2007 by the Plank of Trustees, Southern Illinois University.

E

Eastman, C. M. 1975. The use of computers instead of drawings in building design. *Journal of the American Institute of Architects,* March, pp.46-50.

Eastman, C. T., Teicholz, P. S. and Sacks, R. R. and Liston K. 2008. "BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors".

Eberschweiler, B. 1990. Blockbauten im spätbronzezeitlichen Dorf von Greifensee-Böschen. *Aus: Die ersten Bauern. Pfahlbaufunde Europas*, *1*, 193-200.

Eberschweiler, B., Riethmann, P., Ruoff, U., Veszeli, M. and Plogmann, H. H. 2007. *Das spätbronzezeitliche Dorf von Greifensee-Böschen: Dorfgeschichte, Hausstrukturen und Fundmaterial*. Baudirektion Kanton Zürich.

Economou, M. and Tost, L. P. 2011. Evaluating the use of virtual reality and multimedia applications for presenting the past, pp. 223-239.

Edwards, P. C. and E. House. 2007. The third season of investigations at the Pre-Pottery Neolithic A site of Zahrat adh Dhra' 2 on the Dead Sea plain, Jordan. *Bulletin of the American School of Oriental Research* 347:1–19.

Egenter, N. 2006. *Architectural Anthropology*. In Encyclopaedia of Anthropology, ed. H. J. Birx, Sage publications.

Eilam, E. 2005. Reversing: Secrets of Reverse Engineering. Wiley Publishing, Indianapolis (IN).

Ekstrom, R. B., French, J. W., Harman, H. H. and Dermen, D. 1976. Manual for kit of factor-referenced cognitive tests. *Princeton, NJ: Educational testing service*.

Ellis, L. (Ed.). 2000. *Archaeological Method and Theory*. New York: Garland Publishing.

F

Ferme, L. C. and Piqué, R. 2014. Landscape and forest exploitation at the ancient Neolithic site of La Draga (Banyoles, Spain). *The Holocene*, 24(3), 266.

Figueroa, F. J. P. 2016. Bòbila Madurell-Mas Duran: Formas de vida en el Neolítico medio y final del nordeste peninsular. PhD Thesis. Barcelona, Universitat Autònoma de Barcelona.

Filley, T. R., Blanchette, R. A., Simpson, E. and Fogel, M. L. 2001. Nitrogen cycling by wood decomposing soft-rot fungi in the "King Midas tomb," Gordion, Turkey. *Proceedings of the National Academy of Sciences*, 98(23), 13346-13350.

Fisher, C. 2009. *The exploration of the nature and understanding of family and domestic violence within Sudanese, Somalian, Ethiopian, Liberian and Sierra Leonean Communities and its impact on individuals, family relations, the community and settlement.* Perth, Australia: Association for Services to Torture and Trauma Survivors.

Flannery, K. V. 1972. "*The origins of the village as a settlement type in*

Mesoamerica and the Near East: a comparative study”. In Man, settlement, and urbanism, (Eds.). P. J. Ucko, R. Tringham and G. W. Dimbleby, 23–53. London: Duckworth.

Foley, J.D., van Dam, A., Feiner, S.K. and Hughes, J.F. 1990. *Computer Graphics: Principles and Practice,* 2nd Ed, Addison Wesley, Reading, MA.

Fontijn, D.R. 2007. The significance of ‘invisible’ places. *World Archaeology* 39.1:70-83.

Forman, R.T.T., Godron, M. 1986. *Landscape Ecology*. John Wiley. New York

Forte, M. 1997 (Ed.) *Virtual Archaeology*, (forward by Colin Renfrew) Thames & Hudson Ltd, 1997 (1st edition 1996, Milan).

Forte, M. 2000. About virtual archaeology: disorders, cognitive interactions and virtuality, in Barceló, J.A., Forte, M. and Sanders, D.H., (Eds.), *Virtual Reality in Archaeology*, Oxford, BAR International Series 843, pp. 247-59.

Forte, M. 2008. Cyber-archaeology: an eco-approach to the virtual reconstruction of the past. In *Proceedings of International Symposium on Information and Communication Technologies in Cultural Heritage, Ioannina, Greece*, pp. 91-106.

Forte, M. (Ed.) 2010) *Cyber-archaeology*. Oxford: Archaeopress.

Forte, M. 2011. Cyber-Archaeology: Notes on the simulation of the past. *Virtual Archaeology Review*, *2*(4):7-18.

Forte, M. 2014a. 3D archaeology: new perspectives and challenges—the example of Çatalhöyük. *Journal of Eastern Mediterranean Archaeology & Heritage Studies*, 2(1), 1-29.

Forte, M. 2014b. Visualizing Mediterranean Archaeology. *In Encyclopedia of Global Archaeology*, pp. 7647-7657. Springer New York.

Forte, M. 2014c. Cyber-archaeology: a post e virtual perspective (forthcoming). In: Godberg, D., Svensson, P. (Eds.), *Humanities and the Digital. A Visioning Statement*. MIT Press, Cambridge (Boston).

Forte, M. 2016. Cyber Archaeology: 3D Sensing and Digital Embodiment. En *Digital Methods and Remote Sensing in Archaeology*. Springer International Publishing, pp. 271-289.

Forte, M. and Pescarin, S. 2006. Behaviours, Interactions and Affordance in Virtual Archaeology. *Advanced ICT Methods Guide*.

Forte, M., Pescarin, S. and Pietroni, E. 2006. Transparency, interaction, communication and open source in Virtual Archaeology. *BAR International Series*, 1568, 535.

Forte, M., Dell'Unto, N., Issavi, J., Onsurez, L. and Lercari, N. 2012. 3D archaeology at Çatalhöyük. International Journal of Heritage in the Digital Era, 1(3), 351-378.

Forte, M., Dell'Unto, N., Jonsson, K. and Lercari, N. 2015. Interpretation process at Çatalhöyük using 3D.

Fraaij, A.L.A., Bijen J.M.J.M., Hendriks F., Rooij M. de. 2007. *Duurzame bouwmaterialen*, TU Delft.

Freeman, L.G., Jr. 1968. A theoretical framework for interpreting archaeological materials. In Lee, R. B., and DeVore, I. (Eds.), *Man the Hunter*, *Aldine*, Chicago, pp. 262–267.

Frischer, B., Niccolucci, F., Ryan, N. S. and Barcelò, J. A. 2002. From CVR to CVRO: the past, present, and future of cultural virtual reality. *BAR International Series*, 1075:7-18.

Fuertes, J. L., González, Á. L., Mariscal, G. and Ruiz, C. 2005. Aplicación de la Realidad Virtual a la difusión de la cultura: La Alhambra Virtual. In *Proceedings of the VI Congreso de Interacción Persona Ordenador (AIPO), INTERACCION*, pp. 367-371.

Fulk, J., Steinfeld, CW. 1997. (Eds.). *Organizations and Communication Technology,* Sage. Newbury Park, C.

G

Garašanin, M. and M. Bilbija. 1988. Kuća 1 vo Zelenikovo. *Macedonia Acta Archaeologica* 9:31– 41.

Garbacz-Klempka, A., Kwak, Z., Żak, P. L., Szucki, M., Ścibior, D., Stolarczyk, T. and Nowak, K. 2017. Reconstruction of the Casting Technology in the Bronze Age on the Basis of Investigations and Visualisation of Casting Moulds. *Archives of Foundry Engineering*, 17(3):184-190.

Garfinkel, Y. 1988. Burnt lime products and social implications in the Pre-Pottery Neolithic B villages in the Near East. *Paléorient* 13:69–76.

Gasco, J. 1976. *La communauté paysanne de Fontbuisse*. Laboratoire de Préhistoire et Palethnologie, Carcassonne.

Gebel, H.-G. K., H. J. Nissen and Z. Zaid, (Eds.). 2006. *Basta II. The architecture and stratigraphy. Vol. 5.* Berlin, Biblioteca Neolithica Asiae Meridionalis et Occidentalis & Yarmouk University.

Gebel, H.-G. K. and B. D. Hermansen. 2004. Ba‘ja 2003: summary of the 5th season of excavation. *Neo-Lithics* 2:15–18.

Gennep, A. V. 1981. I riti di passaggio. *Universale scientifica Boringhieri*.

Ghislanzoni, E. 1955. Note sulla struttura della palafitta di Ledro e di altre stazioni lacustri dell’Italia Milano: Hoepli, 1955 Umfang b 4’Reihe (Memorie dell’Istituto Lombardo di Scienze e Lettere. Cl. di lettere, scienze morali e storiche; vol. 25, fasc. 4). Hoepli.

Giachi, G., Secci, M. M., Pignatelli, O., Gambogi, P. and Lippi, M. M. 2010. The prehistoric pile dwelling settlement of Stagno (Leghorn, Italy): wood and food resource exploitation. *Journal of Archaeological Science*, *37*(6):1260-1268.

Gigliarelli, E., Calcerano, F., Calvano, M., Ruperto, F., Sacco, M., Cessari, L. 2017. Integrated numerical analysis and Building Information Modeling forCultural Heritage. Pre-prints of BSA 2017 - Building Simulation Apllications.

Gimbutas, M. (Ed.) 1976. *Neolithic Macedonia as reflected by excavation at Anza, southeast Yugoslavia*. Los Angeles: The Regents of the University of California.

Gleirscher, P. 2014 Keutschach und die Pfahlbauten in Slowenien und Friau - UNESCO-*Welterbestätten* (Klagenfurt, Celovec-Ljubliana, Laibach-Wien, Dunaj 2014).

Gollnisch-Moos, H. 1999. *Ürschhausen-Horn: Haus-und Siedlungsstrukturen der spätestbronzezeitlichen Siedlung*. Amt für Archäologie.

Golvin, J. C. 2003. La restitution de l'image des villes antiques. le probleme de la representation des parties non visibles. In: *Actes du Colloque Virtual Retrospect*. Robert Vergnieux & Caroline Delevoie, pp. 39-43.

Golvin, J. C. 2005. Architecte, D. P. L. G., & Urbaniste, D. I. U. P. 2005. L'image de restitution et la restitution de l'image.

Gomes, M.V. 2013. Castelo Belinho's village (Portimão Algarve) and the sea: Landscape resources and symbols. *Pré-História das Zonas Húmidas. Paisagens de Sal, Setúbal, MAEDS*, pp.69-84.

González López, M. J. and Martínez Calvo, V. 2009. Puesta a punto de un sistema de reintegración virtual de las lagunas. Las pinturas de la Sala de los Reyes de la Alhambra de Granada. PH: *boletín del Instituto Andaluz del Patrimonio Histórico*, (70):98-113.

González-Marcén, P., Martín, A. y Mora, R. 1999. *Can Roqueta: Un establiment pagès prehistòric i medieval*. Barcelona, Generalitat de Catalunya. Dpt. de Cultura.

Goren, Y. and A. N. Goring-Morris. 2008. Early pyrotechnology in the Near East: experimental lime plaster production at the PPNB site of Kfar HaHoresh, Israel. *Geoarchaeology* 23:779–798.

Goring-Morris, A. N. 1993. From foraging to herding in the Negev and Sinai: the Early to Late Neolithic transition. *Paléorient* 19:63–87.

Goring-Morris, A. N., & A. Belfer-Cohen. 2013. *Houses and Households: A Near Eastern Perspective*. In D. Hofmann and J. Smyth (Eds.), Tracking the Neolithic house in Europe - sedentism, architecture and practice. Pp. 19-44. Springer, New York.

Gowing, P. G. 1979. *Muslim Filipinos: Heritage and horizon*. Quezon City, New Day.

Gould, R. A. 1971. The archaeologist as ethnographer: a case from the Western Desert of Australia. *World Archaeology*, 3(2):143-177.

Gould, R.A. 1978. Beyond analogy in ethnoarchaeology. *Explorations in ethnoarchaeology*, 249:93.

Gould, R. A. 1980. *Living archaeology*. CUP Archive.

Gould, R.A., & Watson, P. J. 1982. A dialogue on the meaning and use of analogy in ethnoarchaeological reasoning. *Journal of Anthropological Archaeology*, 1(4):355-381.

Grbić, M., P. Mačkić, S. Nadj, D. Simoska and B. Stalio. 1960. *Porodin: Kasno-neolitsko naselje na Tumbi kod Bitolja*. Bitolj: Narodni muzej Bitolj i Arheološki institute, Beograd.

Green, E. 1973. The use of analogy for interpretation of Maya prehistory. *Journal of the Steward Anthropological Society*, 4:139–159.

Griggs, C., Kuniholm, P. I. and Newton, M. W. 2001. *Lavagnone, Italy: a four-phase tree-ring chronology from the Early Bronze Age*. In: Kaennel Dobbertin M. & Bräker O. U. (Eds) Tree Rings and People. Abstracts of the International Conference, Davos, 22–26 September 2001, 52. (Birmensdorf).

Gronenborn, D. 1999. A variation on a basic theme: the transition to farming in southern central Europe. *Journal of World Prehistory* 13: 123–210.

Gros, P. 1985. La restitution monumentale en architecture romaine: quelques problèmes de méthode. *Revue Archéologique*, 1:177-185.

Gwilt, J. 1851. *An Encyclopaedia of Architecture, Historical, Theoretical, and Practical*. Longman, Brown, Green, and Longmans.

H

Hanafi, Z. 1994. Housing Design in Relation to Environmetal Comfort - A Comparison of the Traditional Malay House and Modern Housing. *Building Research and Information*, *Volume* 22.

Habu, J., Kim M., Katayama, M. and Komiya, H. 2001. Jomon subsistence-settlement systems at the Sannai Maruyama site. *Bulletin of the Indo-Pacific Prehistory Association* 21: 9-21.

Hafner, A. 2011. Neolithic and Bronze Age pile dwelling sites of Lake of Biel. Twenty years of rescue excavations at Sutz-Lattrigen (Canton of Bern/Switzerland). *Notizie Archeologiche Bergomensi*, 19:41-48.

Hafner, A. 2012. *Sutz-Lattrigen, Lake Biel, Switzerland. Twenty years of rescue excavations and in situ conservation.* In: Henderson, Jon (Ed.) Beyond Boundaries. Proceedings of the 3rd International Congress on Underwater Archaeology. Kolloquien zur Vor- und Frühgeschichte, 17:337-344. Bonn, Habelt.

Hafner, A. 2013. Zwischen Gipfeln und Seen-Archäologie im Alpenraum. *UniPress-Forschung und Wissenschaft an der Universität Bern*, (156), 11-15.

Harding, D. W. 2000. Crannogs and island duns: classification, dating and function. *Oxford Journal of Archaeology* 19.3: 307–17.

Hasenfratz, A., Schnyder, M. and Departement für Erziehung und Kultur Thurgau. 1998. *Das Seebachtal: eine archäologische und paläoökologische*

Bestandsaufnahme. Amt für Archäologie.

Haskins, J.F. 1957. Pan-po, a Chinese Neolithic Village. *Artibus Asiae*, 20(2/3), pp.151-158.

Hayden, B. 1998. Practical and Prestige Technologies: The Evolution of Material Systems. *Journal of Archaeological Method and Theory*, 5:1-55.

Hayes, W. C. 1966. Egypt: internal affairs from Tuthmosis I to the death of Amenophis III. 1 (Vol. 1). CUP Archive.

Heim, M. 1993. *The metaphysics of virtual reality*. Oxford University Press on Demand.

Heim, M. 1995. The design of virtual reality. *Body & Society*, *1*(3-4):65-77.

Heim, M. 2000. *Virtual realism*. Oxford University Press.

Heim, M. 2001. The Feng Shui of virtual environments. *Crossing 1 (1)*.

Heim, M. 2014. *The paradox of virtuality*. In Mark Grimshaw (Ed.) The Oxford Handbook of Virtuality, pp. 111-125. Oxford University Press: New York, NY, USA.

Heizer, R.F. 1941. The direct-historical approach in California archaeology. *American Antiquity*, 7:98–122.

Henderson, J. C. 1998. Islets through time: the definition, dating and distribution of Scottish crannogs. *Oxford Journal of Archaeology* 17.2: 227–44.

Henderson, J. C., Sands, R. 2013. Irish and Scottish crannogs, in F. Menotti & A. O'Sullivan (ed.) *The Oxford handbook of wetland archaeology*: 269–82. Oxford, Oxford University Press.

Henderson, J. C., Crone, B. A. and Cavers, G. 2003. A condition survey of selected crannogs in south west Scotland. *Transactions of the Dumfriesshire and Galloway Natural History and Antiquarian Society,* 77: 79–102.

Henry, D. O. 2005. Ayn Abu Nukhayla: Early Neolithic adaptation to the arid zone. *Journal of the Israel Prehistoric Society* 35:353–370.

Hermon, S. 2008. Reasoning in 3D: a Critical Appraisal of the Role of 3D Modelling and Virtual Reconstructions in Archaeology. In: *Beyond Illustration: 2D and 3D Digital Technologies as Tools for Discovery in Archaeology*, pp: 36-45.

Hermon, S. 2012. Scientific Method, chaine operatoire, and Visualization: 3D Modelling as a Research Tool in Archaeology. In Bentkowska-Kafel, A., Denard, H. & Baker, D. (Eds.). *Paradata and Transparency in Virtual Heritage*. London: Ashgate.

Hermon, S., Niccolucci, F., D'Andrea, A. 2005. Some evaluations on the potential impact of virtual reality on the archaeological scientific research. In: *Proc. VSMM 2005*, pp: 105-114.

Hermon, S., Nikodem, J., 2007. 3D modeling as a scientific research tool in archaeology. In: *International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA)*, pp: 1-6.

Hermon, S. and Kalisperis, L. 2011. Between the Real and the Virtual: 3D visualization in the Cultural Heritage domain-expectations and prospects. *Virtual Archaeology Review*, 2(4), 59-63.

Heywood, T. R., Galton, B. N., Gillet, J., Morffew, A. J., Quardendon, P., Todd, S. P. J. and Wright, W. V. 1984. The Winchester graphics system: a technical overview; *Computer Graphics Forum*, 3:61–70.

Hillier, B., & Hanson, J. 1984. *The Social Logic of Space*. Cambridge University Press. Cambridge.

Hirmann, H. 1999. Unterwasserarchäologische Fundstellen in Österreich. B.A. Thesis University of Vienna 1999

Hodder, I. 1982. *Symbols in Action: Ethnoarchaeological Studies of Material Culture*. Cambridge: Cambridge University Press.

Hodder, I. and Cessford, C. 2004. Daily Practice and Social Memory at Çatalhöyük. *American Antiquity* 69:17–40.

Hofmann, D. 2013. Narrating the house. The transformation of longhouses in early Neolithic Europe. *Memory, Myth and Long-Term Landscape Inhabitation*. Oxford, Oxbow, pp.32-54.

Hole, F. 1978. Pastoral nomadism in western Iran. *Explorations in ethnoarchaeology*, 127-167.

Horne, L. C. 1988. The spatial organization of rural settlement in Khar o Tauran, Iran: An ethnoarchaeological case study.

Недомолкина, Н. and Пьецонка, Х. 2014. свайная конструкция поселения векса iii на реке вологде: структура и датировка. археолоГия озерных Поселений iV–ii тыс. до н. Э., p.304.

Недомолкина Н.Г. 2006. Место неолитических памятников Верхней Сухоны в неолите лесной зоны Европейской части России. (По материалам комплекса многослойных поселений Векса) // II Северный археологический конгресс. Тезисы докладов. Екатеринбург, Ханты-

Мансийск. С. 59–60.

Недомолкина Н.Г., Пиецонка Х. 2010. Многовариантный анализ и распространение неолитической посуды в лесной зоне: на примере памятника Векса 3, северо-запад России // III. Северный Археологический Конгресс: Тезисы докладов. Екатеринбург, Ханты-Мансийск. С. 117–119.

Hsing-pang, S. 1959. Pan-Po: Largest Neolithic Site In China Unearthed. *Revue Archéologique*, 2:1-14.

Hurt, T.D., Rakita, G.F.M. (Eds.) 2001. Style & Function: Conceptual Issues in *Evolutionary Archaeology*. Bergin & Garvey, Westport (CT).

I

Imamura, M. 1999. Koseido 14C nendai sokutei to kokogaku (High precision 14C dating and archaeology). *Gekkan Chikyu*, pp.23-31.

Imamura K. 1996. *Prehistoric Japan*. University College of London Press.

J

Jacomet, S. and Brombacher, C. 2005. Reconstructing intra-site patterns in Neolithic lakeshore settlements: the state of archaeobotanical research and future prospects. *WES*, 4:6.

Jakhelln, G. 2014. December. Givaer Island, on the artic coast of Norway—a multifaceted economy surviving on heritage skills. In *Vernacular heritage and earthen architecture: Contributions for sustainable development* (pp. 23-28).

Jennings, B. 2014. *Breaking with Tradition: Cultural influences for the decline of the Circum-Alpine region lake-dwellings*. Sidestone Press. Leiden.

Jiang, L. and Liu, L. 2006. New evidence for the origins of sedentism and rice domestication in the Lower Yangzi River, China. *Antiquity*, 80(308):355.

Jeunesse, C. 1997. À propos de la signification historique des dépots dans le Néolithique danubien ancien et moyen. In B. Fritsch, M. Maute, I. Matuschik, J. Müller, and C. Wolf (Eds.), *Tradition und Innovation: prähistorische Archäologie als historische Wissenschaft. Festschrift für Christian Strahm*, 31–50. Rahden, Marie Leidorf.

Jun, L.I.U, 1985. Some observations on the archaeological site of Hemudu, Zhejiang Province, China. *Bulletin of the Indo-Pacific Prehistory Association*, 6:40-45.

K

Kantner, J. and Hobgood, R. 2003. Digital technologies and prehistoric landscapes in the American Southwest. *BAR INTERNATIONAL SERIES*, 1151: 117-124.

Kantner, J. 2010. Implications Of Human Behavioural Ecology For Understandign Complex Human Behaviour: Resource Monopolization, Package Size, and Turquoise. *Journal of Anthropological Research*, *66*(2), 231-257.

Kazhdan, M., Bolitho, M. and Hoppe, H. 2006. Poisson Surface Reconstruction. In: *Symposium on Geometry Processing*, Sardinia, pp. 61–70.

Kensek, K. M. 2007. A Survey of Methods for Showing Missing Data, Multiple Alternatives, and Uncertainty in Reconstructions. *CSA Newsletter*, *19*(3).

Kilikoglou, V., Vekinis, G., Maniatis, Y. and Day, P. M. 1998. Mechanical performance of quartz-tempered ceramics: part I, strength and toughness.

Archaeometry, 40(2):261-279.

Kilikoglou, V., Vekinis, G. 2002. Failure Prediction and Function Determination of Archaeological Pottery by Finite Element Analysis. *Journal of Archaeological Science* 29:1317-1325.

Kolištrkovska Nasteva, I. 2005. *Praistoriskite dami od Makedonija*. Skopje, Muzej na Makedonija.

Kinzel, M., A. Abu-Laban, C. H. Jensen, I. Thuesen and M.-L. Jorkov. 2011. Insights into PPNB architectural transformation, human burials, and initial conservation works: summary on the 2010 excavation season at Shkarat Msaied. *Neo-Lithics* 1(11):44–49.

Kirsh, D. 2009. Explaining Artefact Evolution. In *Cognitive Life of Things: Recasting the Boundaries of the Mind*. L. Malafouris (Ed.), McDonald Institute for Archaeological Research, Cambridge University press.

Kitanoski, B., D. Simoska and J. Todorović. 1987. Radin Dol: Neolitska naselba kaj Prilep. *Macedoniae Acta Archaeologica* 7/8:7–29.

Koskela, L. 2008. Is a theory of the built environment needed? *Building Research & Information*, 36(3):211-215

Koukouli-Chrysanthaki, C., R. Treuil and D. Malamidou. 1996. Proistorikos oikismos Philippon 'Dikili Tash': Deka hronia anaskafikis erevnas. *Archaiologiko Ergo sti Makedonia kai Thraki* 10B:681–704.

Колосова, М. И. Мазуркевич, А. Н. 1998. Идентифика- ция деревянных предметов по признакам анатомического строения древесины из неолитических торфяниковых па- мятников Ловатско-Двинского междуречья // Поселения: среда, культура, социум. СПб.

Kramer, C. 2014. *Village ethnoarchaeology: rural Iran in archaeological perspective*. Academic Press.

Kriiska, A. and Roio, M. 2011. Prehistoric archaeology of wetlands in Estonia. *Wetland Settlements of the Baltic. A Prehistoric Perspective*, 55-73.

Kuijt, I. and B. Finlayson. 2009. Inventing storage: evidence for the earliest pre-domestication granaries 11,000 years ago in the Jordan Valley. *Proceedings of the National Academy of Sciences of the United States of America* 106:10,966–10,970.

Kuilen J.W.G van der, Vries P.A. de. 2005. *Constructieleer 3A -CT3051A*, TU Delft.

L

Lane, P. 2014. *Hunter-gatherer-fishers, ethnoarchaeology and analogical reasoning* (pp. 104-150). Oxford: Oxford University Press.

Lange, F.W. 1980. Prehistory and hunter/gatherers: The role of analogs. *Midcontinental Journal of Archaeology*, 5:133–147.

Lanier, J. 1992. Virtual reality: The promise of the future. *Interactive Learning International*, *8*(4): 275-79.

Laroche, F., Bernard, A. and Cotte, M. 2008. Advanced industrial archaeology: a new reverse-engineering process for contextualising and digitising ancient technical objects. *Virtual and Physical Prototyping*, 3(2):105-122.

Larsson, M. 1992. The Early and Middle Neolithic Funnel Beaker culture in the

Ystad area (southern Scania). Economic and social change, 3100–2300 BC. In *The archaeology of the cultural landscape. Fieldwork and research in a south Swedish rural region*, (Eds.). L. Larsson, J. Callmer and B. Stjernquist, 17–90. Stockholm: Almqvist & Wiksell International.

Larsson, L. and Brink, K. 2012. *Lost and Found: Houses in the Neolithic of Southern Scandinavia*. In D. Hofmann and J. Smyth (Eds.). Tracking the Neolithic house in Europe - sedentism, architecture and practice. Pp. 329-347. Springer, New York.

Lawrence, D.L. and Low, S.M. 1990. The built environment and spatial form. *Annual review of anthropology*, 19(1):453-505.

Lechevallier, M. and A. Ronen. 1994. *Le gisement de Hatoula en Judée occidentale, Israel*. Paris: Association Paléorient.

Lercari, N., Shiferaw, E., Forte, M. and Kopper, R. 2017. Immersive Visualization and Curation of Archaeological Heritage Data: Çatalhöyük and the Dig@ IT App. *Journal of Archaeological Method and Theory*, 1-25.

Lavender, D., Wallis, A., Bowyer, A. and Davenport, P. 1990. Solid modelling of roman Bath. *Science and archaeology,* 32:15-19.

Levy, R. and Dawson, P. 2006. Reconstructing a Thule whalebone house using 3D imaging. IEEE MultiMedia, 13(2):78-83.

Levy, R. M. and Dawson, P. C. and Arnold, C. 2004. Reconstructing traditional Inuit house forms using three-dimensional interactive computer modelling. *Visual Studies,* 19(1):26-36.

Levy, T. E., Najjar, M. and Ben-Yosef, E. 2014. *New Insights Into the Iron Age Archaeology of Edom, Southern Jordan: Surveys, Excavations and Research* *from the University of California, San Diego & Department of Antiquities of Jordan, Edom Lowlands Regional Archaeology Project (ELRAP)*. Cotsen Institute of Archaeology Press.

Leyton, M. 1992. *Symmetry. Causality, Mind*. The MIT Press, Cambridge (MA).

Leyton, M. 2003. *A generative theory of shape* (Vol. 2145). Springer.

Liu, L., Chen, X. 2012. *The archaeology of China: from the late Paleolithic to the early Bronze Age*. Cambridge University Press.

López, O. 2015. *Processos d'obtenció, transformació i ús de la fusta en l'assentament neolític antic de la Draga (5320-4800 cal BC)*. Ph.D. dissertation, Dep. Archeol. Prehist. Univ. Autònoma de Barcelona.

Lopez Bendicho, V. M. M. and Grande, A. 2011. Hacia una carta internacional de arqueología virtual. El borrador SEAV. Virtual Archaeology Review, 2(4):71-75.

Lopez Bendicho, V. M. M. 2013. International guidelines for virtual archaeology: the Seville principles. In *Good Practice in Archaeological Diagnostics*, pp.269-283. Springer International Publishing.

Lopez Bendicho, V. M. M, Gutiérrez, M. F., Vincent, M. L. and León, A. G. 2017. Digital Heritage and Virtual Archaeology: An Approach Through the Framework of International Recommendations. In *Mixed Reality and Gamification for Cultural Heritage*, pp.3-26. Springer International Publishing.

Lourenço, P. B. 2001. Analysis of historical constructions: from thrust-lines to advanced simulations. *Historical constructions*, 7-9.

Lundstrom-Baudais, K., 1986. Étude paléoethnobotanique de la Station III de

Clairvaux, in Pétrequin P. (sous la direction de), *Les sites littoraux néolithiques de Clairvaux-les-Lacs (Jura), tome 1, Problématique générale, l'exemple de la station III, Éditions de la Maison des Sciences de l'Homme,* Paris, pp. 311- 391

Lüning, J. 2000. *Steinzeitliche Bauern in Deutschland: die Landwirtschaft im Neolithikum*. Bonn, Habelt.

Lyman, R.L. and O'Brien, M.J. 2001. Baerreis. (Eds.), Method and Theory in American Archaeology, University of Alabama Press, Tuscaloosa, pp. I-1–I-78.

M

Ma, W. and Kruth, J. P. 1998. NURBS curve and surface fitting for reverse engineering. *The International Journal of Advanced Manufacturing Technology*, *14*(12):918-927.

Madsen, T. and H. J. Jensen. 1984. Settlement and land use in Neolithic Denmark. *Analecta Praehistorica Leidensia* XV: 63–86.

Magny, M., Galop, D., Bellintani, P., Desmet, M., Didier, J., Haas, J.N., Martinelli, N., Pedrotti, A., Scandolari, R., Stock, A.., Vannière, B. 2009. Late-Holocene climatic variability south of the Alps as recorded by lake-level fluctuations at Lake Ledro, Trentino, Italy. *The Holocene* 19 (4): 575-589.

Mahasneh, H. M. 1997. A PPNB settlement at As-Sifiya in Wadi al-Mujib. In *Studies in the history and archaeology of Jordan VI*, (Eds.). G. Bisheh, M. Zaghoul and I. Kehrberg, 227–234. Amman: Department of Antiquities.

Mahasneh, H. and H-D. Bienert. 2000. Unfolding the earliest pages of sedentism: the Pre-Pottery Neolithic settlement in es-Sifiya. In *At the crossroads. Essays on the archaeology, history and current affairs of the Middle East*, (Eds.). H.-D. Bienert and B. Müller-Neuhof, 1–13. Amman: German Protestant Institute of Archaeology in Amman.

Manacorda, D., 2007. Il sito archeologico: fra ricerca e valorizzazione (Roma).

Martín, A., Miret, J., Blanch, R. M., Aliaga, S., Enrich, R., Colomer, S., Albizuri, S., Bosch, J. 1988. Campanya d'excavacions arqueològiques 1987-88 al jaciment de la Bòbila Madurell-Can Feu (Sant Quirze del Vallès, Vallès occidental). *Arraona: revista d'història*, (3): 9-23.

Masvidal Fernández, C., Moral Torcal, R. 1999. El poblamiento neolítico en el Vallés (Barcelona): problemática y propuesta para su estudio. *SAGVNTVM Extra*, 2:299-306.

Matthews, R. 1996. Surface Scraping and Planning. In *On the Surface: Çatalhöyük* 1993–5, edited by Ian Hodder, pp. 79–100. McDonald Institute for Archaeological Research/British Institute of Archaeology at Ankara, Cambridge.

Matthews, W. 2005. Micromorphological and Microstratigraphic Traces of Uses and Concepts of Space. In *Inhabiting Çatalhöyük: Reports from the 1995–1999 Seasons*, edited by Ian Hodder, pp. 355–398. McDonald Institute for Archaeological Research/British Institute of Archaeology at Ankara, Cambridge.

Mazurkevich, A. 2013. Das Waldgebiet in Osteuropa am Ende des 4. —Beginn des 2. Jahrtausends v. Chr. //Bronzezeit. Europa ohne grenzen. 4.-1. Jahrtausend v. Chr. Ausstellungskatalog. St. Petersburg.

Mazurkevich, A., Dolbunova, E. 2011. Underwater investigations in Northwest Russia: archaeology of pile dwellings.// ed. J. Benjamin, C. Bonsall, C. Pickard, A. Fischer. *Underwater Archaeology and the Submerged Prehistory of Europe*. Oxbow Books.

McArthur, K. N. and Vandiver, P. B. 2017. Reverse Engineering Eighth Century CE Window Glass Processing at Sardis, Turkey. *MRS Advances*, 1-16.

Medri, M., 2003. Manuale di rilievo archeologico (Roma-Bari).

Mellaart, J. 1967 *Çatal Hüyük: A Neolithic Town in Anatolia*. Thames and Hudson, London.

Menotti, F. 2012. *Wetland archaeology and beyond: theory and practice*. Oxford University Press. Oxford.

Menotti, F. 2004. *Living on the lake in prehistoric Europe: 150 years of lake-dwelling research*. Routledge, London.

Menotti, F. O'Sullivan, A. 2013. *The Oxford Handbook of Wetland Archaeolog*. Oxford University Press. Oxford.

Menotti, F., Baubonis, Z., Brazaitis, D., Higham, T., Kvedaravicius, M., Lewis, H., Motuzaite, G., Pranckenaite, E. 2005. The first lake-dwellers of Lithuania: Late Bronze Age pile settlements on Lake Luokesas. *Oxford Journal of Archaeology* 24 4:363–401.

Menq, C.H. and Yau, H.T. 1991. An intelligent, computer integrated and self sustaining environment for automated dimensional inspection of manufactured parts. *Proc. NSF Design and Manuf. Syst. Conf.*, Austin, TX, pp. 865--872

Miklyaev (Микляев). А.М., 1995. Каменный железный век в меж- дуречье Западной Двины и Ловати // ПАВ № 9. ред. Мазур- кевич А.Н., Короткевич Б.С. СПб.

Miklyaev (Микляев). А.М., 1969. Памятники Усвятского микрорегиона. Псковская область. Археологический сборник, 11:18-40.

Millikan, R.G. 1999. Wings, Spoons, Pills and Quills: A Pluralist Theory of Function. *Journal of Philosophy,* 96:192-206.

Mitkoski, A. 2005. Vrbjanska Čuka kaj seloto Slavej, Prilepsko. *Zbornik na Muzejot na Makedonija* 2:33–46.

Miyamoto, N. 1995. Kyodai bashira iko no shotai [The nature of the feature associated with large posts]. *Jomon Bunka no Hakken: Kyoi no Sannai Maruyama Iseki [Discovery of the Jomon Civilization: Amazing Discoveries at the Sannai Maruyama Site]*, pp.214-2.

Mokhtar, A. S. A., Abdel-Motaal, M. A., & Wahidy, M. M. 2014. Lateral displacement and pile instability due to soil liquefaction using numerical model. *Ain Shams Engineering Journal*, 5(4):1019-1032.

Modderman, P. 1988. The Linear Pottery culture: diversity in uniformity. *Berichten van de Rijksdienst voor het Oudheidkundig Bodemonderzoek* 38: 63–139.

Modderman, P. 1970. Linearbandkeramik aus Elsloo und Stein. *Analecta Praehistorica Leidensia* 3:1–217.

Moffatt, S. and Kohler, N. 2008. Conceptualizing the built environment as a social–ecological system. *Building research & information*, *36*(3):248-268.

Moitinho, V. 2013. *Towards Functional Analysis of Archaeological Objects through Reverse Engineering processes*, Ph.D. Thesis.

Moitinho, V. and Barceló, J.A. 2013. Computer Simulation of Multidimensional Archaeological Artefacts. *Virtual Archaeology Review*, *4*(9):223-229.

Moitinho, V. and Barceló, J. A., Rosillo, R. and Palomo, A. 2013. Linking 3D digital surface texture data with ancient manufacturing procedures. In *Digital Heritage International Congress (DigitalHeritage), 2013* (Vol. 1, pp. 735-738). IEEE.

Morgan, C. L. 2009. (Re)Building Çatalhöyük: Changing virtual reality in archaeology. *Archaeologies*, 5(3): 468.

Moshenska, G. 2016. Reverse engineering and the archaeology of the modern world. In *Forum Kritische Archäologie,* 5:16-28.

Mould, C.A. and K.A. Wardle. 2000. The architectural remains. In *Servia I*, (Eds.). C. Ridley, K.A. Wardle and C.A. Mould, 71–105. London: British School at Athens.

Muris, V. L. C. 2011. *Stilt Houses: Principals of smart design*. TU Delft.

Munson, P.J. 1969. Comments on Binford's "Smudge pits and hide smoking: The use of analogy in archaeological reasoning." *American Antiquity*, 34:83–85.

Murray, T. and Walker, M.J. 1988. Like WHAT? A practical question of analogical inference and archaeological meaningfulness. *Journal of Anthropological Archaeology,* 7:248–287.

Meyersohn, W.D. 1994. Pile response to liquefaction–induced lateral spread. Ph.D. Dissertation, Cornel University, Ithaca, NY.

N

Nai, H. 1963. Archaeology in new China. *Antiquity*, 37(147), pp.176-184.

Nagy, G. 1999. *Ürschhausen-Horn: Keramik und Kleinfunde der* *spätestbronzezeitlichen Siedlung. Text*. Amt für Archäologie.

Naumov, G. 2013. Embodied Houses: the Social and Symbolic Agency of Neolithic Architecture in the Republic of Macedonia. In D. Hofmann and J. Smyth (Eds.), Tracking the Neolithic house in Europe - sedentism, architecture and practice, pp. 65-94. Springer, New York.

Naumov, G. 2009. *Neolithic visual culture and rituals. In Neolithic communities in the Republic of Macedonia*, (Eds.). G. Naumov, Lj. Fidanovski, I. Tolevski and A. Ivkovska, 87–135. Skopje, Dante.

Neamtu, C., Popescu, S., Popescu, D. and Mateescu, R. 2012. Using reverse engineering in archaeology: ceramic pottery reconstruction. *Journal of Automation Mobile Robotics and Intelligent Systems*, 6:55-59.

Neander, K. 1991. The Teleological Notion of Function. *Australian Journal of Philosophy*, 69:454-68.

Nelson, B.A. 1981. Ethnoarchaeology and paleodemography: a test of Turner and Lofgren's hypothesis. *Journal of Anthropological Research* 37:107- 129.

Nicholas, G. P. 2003. Wet Sites, Wetland Sites and Cultural resource Management Strategies pp. 262-270. In *The Enduring Records: the Environmental and Cultural Heritage of Wetlands*. Barbara A. P. (Ed.), Oxbow Books. Oxford.

Nicholas, G.P. 1988. Ecological Leveling: The Archaeology and Environmental Dynamics of Early Postglacial Land Use. In Nicholas G.P. (Ed.). *Holocene Human Ecology in Northeastern North America*, pp: 257-296. Plenum Press. New York.

Niccolucci, F. 2002. *Virtual Archaeology*. Proc. VAST Arezzo, Oxford, BAR

International Series, 1075.

Niccolucci, F. 2012. Setting standards for 3D visualization of cultural heritage. *In Europe and beyond. Paradata Transpar,* pp: 23-36.

Niccolucci, F. and Hermon, S. 2004. A fuzzy logic approach to reliability in archaeological virtual reconstruction. In *Beyond the Artifact–Digital Interpretation of the Past, Proceedings of the CAA2004 Conference, Prato, Italy. Archaeolingua, Budapest*, pp: 26-33.

Nielsen, P. O. and F. O. Nielsen. 1985. Middle and Late Neolithic Houses at Limensgård, Bornholm. A preliminary Report. *Journal of Danish Archaeology* 4:101–114.

Niering, W.A. 1985. *Wetlands*. Knopf. New York.

Nishida, M. 2002. Another Neolithic in Holocene Japan. *Documenta Praehistorica*, 29:21-28.

Novak, H. 2016. Neolithic Lake Settlements A new UNESCO World Heritage leads to the emerging of underwaterand wetland-research in Austria. In: *N.E.R.D., New European Researches and Discoveries in Underwaterarchaeology Conference: Beiträge der internationalen Konferenz der Arbeitsgruppe für maritime und limnische Archäologie*, 21.-23. November 2014 in Kiel; pp: 36-44.

O

Offenberger, J., 1981. Die Pfahlbauten der Salzkammergutseen. *Das Mondseeland. Geschichte und Kultur,* pp.295-357.

Offenberger, J. and Ruttkay, E., 1997. Pfahlbauforschung in den österreichischen Salzkammergutseen. In H. Schlichtherle (ed.) *Pfahlbauten rund um die Alpen*, pp. 76–86. Stuttgart, Theiss.

Okada, Y. 1995. Ento doki bunka no kyodai shuraku [A large settlement from the Ento pottery culture: the Sannai Maruyama site in Aomori Prefecture]. *Kikan Kokogaku* [Archaeology Quarterly], 50:25-30.

Okada, Y. 2003. Jomon culture of northeastern Japan and the Sannai Maruyama site. In *Hunter- Gatherers of the North Pacific Rim*, ed. by J. Habu, J. Savelle, S. Koyama, and H. Hongo, pp. 173-186. Senri Ethnological Studies 63. Osaka: National Museum of Ethnology.

Okada, Y. and Habu, J. 1995. Public presentation and archaeological research: a case study from the Jomon period Sannai Maruyama site. In *Chacmool Conference*, November (Vol. 11).

Oliver, P. 1997. *Encyclopedia of vernacular architecture of the world*. Cambridge: Cambridge University Press.

Orme, B. 1973. Archaeology and ethnography. *The Explanation of Culture Change: Models in Prehistory*. Colin Renfrew, Ed; 481-492.

Ochsenschlager, E. L. 1974. Modern potters at al-Hiba, with some reflections on the excavated Early Dynastic pottery. *Ethnoarchaeology*, 149-57.

O'Sullivan, A. 1998. *The Archaeology of Lake Settlement in Ireland*. Dublin, Royal Irish Academy.

O'Sullivan, A. 2009. Early medieval crannogs and imagined islands. In G. Cooney, K.

Oswalt, W. H. 1974 Ethnoarchaeology. In *Ethnoarchaeology*, edited by C.

Donnan and C. Clewlow, pp. 3-11. University of California, Los Angeles, *Institute of Archaeology*, Monograph IV.

Oswalt, W. H., and J. W. VanStone. 1967. The Ethnoarchaeology of Crow Village, Alaska. Bulletin No. 199. Washington, DC: *Smithsonian Institution Bureau of American Ethnology*.

Ozawa, K. 1988. Zempokeonfun no suri (mathematical approaches to keyhole-shaped tombs). Tokyo.

Ozawa, K. 1993. Reconstruction of Japanese ancient tombs and villages. *Computing the Past. CAA92: Computer Applications and Quantitative Methods in Archaeology, Aarhus University Press, Aarhus*, 415-423.

Ozawa, K. 2002. Computing the Past in Japan.

Ozawa, K. and Kawai, T. 1991. Reconstruction of the Yoshinogari site using three-dimensional computer graphics. In *Archaeology and computers symposium*, Saga Museum, 28–29 May 1991.

P

Palomo, A., Piqué, R., Terradas, X., Bosch, À., Buxó, R., Chinchilla, J., Saña, M., Tarrús, J. 2014. Prehistoric occupation of Banyoles lakeshore: results of recent excavations at La Draga site, Girona, Spain. *Journal of Wetland Archaeology, 14* 1:58-73.

Palomo, A., Piqué, R., Terradas, X., López, O., Clemente, I., Gibaja, J.F. 2013. Woodworking technology in the Early Neolithic site of la Draga (Banyoles, Spain) in Anderson, P.C., Cheval, C., Durand, A. (eds.), *An interdisciplinary focus on plant-working tools*, Antibes: Éditions APDCA, 383-396. [ISBN 2-904110-53-4].

Palomo, A., Gibaja, J.F., Piqué, R., Bosch, A., Chinchilla, J., Tarrús, J. 2011. "Harvesting cereals and other plants in Neolithic Iberia: the assemblage from the lake settlement at la Draga". Antiquity, 85:759–771.

Pang, A. T., Wittenbrink, C. M. and Lodha, S. K. 1997. Approaches to uncertainty visualization. *The Visual Computer*, *13*(8):370-390.

Papadopoulos, C. and Earl, G. 2014. Formal three-dimensional computational analyses of archaeological spaces. *Spatial analysis and social spaces: interdisciplinary approaches to the interpretation prehistoric and historic built environments* (Eds. E. Paliou, U. Lieberwirth, S. Polla). De Gruyter, Berlin, pp.135-165.

Papadopoulos, C. and Earl, G. P. 2009. Structural and lighting models for the Minoan cemetery at Phourni, crete. In *Proceedings of the 10th International conference on Virtual Reality, Archaeology and Cultural Heritage,* pp.57-64. Eurographics Association.

Papadopoulos C. and Sakellarakis Y. 2013. Virtual windows to the past: reconstructing the 'ceramics workshop' at Zominthos, Crete, in Melero J., Cano P. & Revelles J. (ed.) *CAA 2010 Proceedings of Computer Applications & Quantitative Methods in Archaeology*. pp.47–54. (British Archaeological Reports British series 2949). Oxford: Archaeopress.

Paret, O. 1958. *Le Mithe des Cités Lacustres.* Paris, Dunod.

Pawlik, B. 1993. *Die botanische Untersuchung der jungneolithischen Feuchtbodensiedlung Station See am Mondsee, Oberösterreich*. Teilergebnisse, Bericht 1993 für das Pfahlbauprojekt. Vienna, Manuskript.

Pescarin, S. 2014. Virtual Reality & Cyberarchaeology-Virtual Museums. *3D*

Recording and Modelling in Archaeology and Cultural Heritage, 130.

Pescarin, S., Forte, M., Calori, L., Camporesi, C., Guidazzoli, A. and Imboden, S. 2005. Open Heritage: an Open Source approach to 3d real-time and web-based landscape reconstruction. In *VSMM2005. Proceedings of the 11th International Conference on Virtual Systems and Multimedia: Virtual Reality at Work*, pp. 313-320.

Pescarin, S., Palombini, A., Vassallo, V., Calori, L., Camporesi, C., Fanini, B. and Forte, M. 2009. *Virtual Rome*. In CAA 2009 Proceedings.

Pescarin, S., Fanini, B., Ferdani, D., Baldassari, G. L. and Calori, L. 2011. Archeologia virtuale, realismo, interattività e performance: dalla ricostruzione alla fruizione on line. *DisegnareCon*, 4(8):62-70.

Pétrequin, P. 1988. L'architecture lacustre du Néolithique moyen II au Nord-Ouest des Alpes: les contraintes du milieu, de l'organisation sociale et des modes de faire-valoir agricoles. *Bulletin de la Société préhistorique française*, 367-389.

Pétrequin, A.M., Pétrequin, P. 1988. *Le Néolithique des lacs: préhistoire des lacs de Chalain et de Clairvaux (4000-2000 av. J.-C.)*. Éd. Errance.

Pierce, C. 2005. Reverse engineering the ceramic cooking pot: cost and performance properties of plain and textured vessels. Journal of Archaeological Method and Theory, 12(2), 117-157.

Piqué, R.; Palomo, A.; Terradas, X.; Tarrús, J.; Bosch, A.; Chinchilla,J.; Bodganovic, I.; López, O., Saña, M. 2015. Characterizing prehistoric archery: technical and functional analyses of the Neolithic bows from La Draga (NE Iberian Peninsula). *Jounal of Archaeological Science* 55, 166–173.

Piqué, R., Romero, S., Palomo, A., Tarrús, J., Terradas, X. and Bogdanovic, I.

2016. The production and use of cordage at the early Neolithic site of La Draga (Banyoles, Spain). *Quaternary International*.

Pletinckx, D. 2011. Virtual archaeology as an integrated preservation method. *Virtual Archaeology Review*, *2*(4):33-37.

Pletinckx, D. 2012. How to make sustainable visualizations of the past: an EPOCH common infrastructure tool for interpretation management. *Paradata and transparency in virtual heritage. Ashgate, Farnham*, 203-242.

Pollini, J., Dodd, L.S., Kensek, K., Cipolla, N. and Institute, G.R. 2005. Problematics of making ambiguity explicit in virtual reconstructions: a case study of the Mausoleum of Augustus. In: *Theory and Practice : Proceedings of the 21st Annual Conference of CHArt: Computers and the History of Art*. British Academy, Londres.

Poster, M. 2001. *What's the matter with the internet?, Minneapolis: University of Minnesota Press. Pfeffer, Jeffrey and Sutton, Robert, I. (1999) The Knowing–Doing Gap: How Smart Companies Turn Knowledge Into Action*. Cambridge, MA: Harvard University Press.

Pramar, V.S. 1973. *Design Fundamentals in Architecture*. Somaiya Publications, New Delhi.

Pujol-Tost, L. 2011. Realism in Virtual Reality applications for Cultural Heritage. *International Journal of Virtual Reality*, 10(3).

Pujol-Tost, L. 2016. Pixel vs Pigment. The goal of Virtual Reality in Archaeology.

Pujol-Tost, L. 2017. "3D· Cod": A New Methodology for the design of Virtual Reality-Mediated experiences in digital Archeology. *Frontiers*, 4(16): 1.

Pujol-Tost, L. and Economou, M. 2009. Worth a thousand words? The usefulness of immersive virtual reality for learning in cultural heritage settings. *International Journal of Architectural Computing*, 7(1), 157-176.

Purcell, A. 2002. Excavation of three Neolithic houses at corbally, Kilcullen, co. Kildare. *The Journal of Irish Archaeology*, pp.31-75.

R

Raja, V., Fernandes, K.J. (Eds.). 2008. *Reverse Engineering: An Industrial Perspective*. Springer-Verlag, London.

Rabeneck, A. 2008. A sketch-plan for construction of built environment theory. *Building Research & Information*, *36*(3):269-279.

Rasmussen, M. 2011. Under the same roof. In Petersson, B. & Narmo, L. E. (Eds.) *Experimental archaeology: between enlightenment and experience*. Lund: LundUniversity, Department of Archaeology and Ancient History.

Rapoport, A. 1977. *Human aspects of urban form* (Vol. 3). Oxford, Pergamon.

Rapoport, A. 1970. The study of spatial quality. *Journal of Aesthetic Education*, 4(4):81-95.

Rapoport, A. 1969. *House Form and Culture*. Prentice-Hall.

Rheingold, H. 1991. *Virtual reality: exploring the brave new technologies*. Simon & Schuster Adult Publishing Group.

Reilly, P. 1989. Data visualization in archaeology. *IBM systems journal*, 28(4): 569-579.

Reilly, P. 1991. ‘Towards a virtual archaeology’. In *CAA90. Computer Applications and Quantitative Methods in Archaeology 1990.* Edited by S. Rahtz & K. Lockyear, pp. 132–139. BAR International Series 565. Oxford: Tempus Reparatum.

Reilly, P. 1992. Three-dimensional modelling and primary archaeological data. In *Archaeology in the Information Age: a global perspective*. Edited by P. Reilly & S. Rahtz, pp: 145–173. London: Routledge.

Reilly, P. 2013. Towards a virtual archaeology CAA1990 abridged. http://vimeo.com/77871447, Accessed 28 August 2014.

Reilly, P. and Shennan, S. 1989. *Applying solid modelling and animated three-dimensional graphics to Archaeological problems*. IBM UK Scientific Centre.

Reina, R.E.; Hill, R.M. 1978. *The traditional pottery of Guatemala*. University of Texas Press.

Reinerth, H. 1932. Das Pfahlbaudorf Sipplingen. Ergebnisse der Ausgrabungen des Bodenseegeschichtvereins, 1929-1930. Führer zur Urgeshcichte 10. Leipzig: Kurt Kabitsch.

Revelles, J.,Burjachs, F., Morera, N., Barceló, J.A., Berrocal, A., López-Bultó, O., Maicher, C., Le Bailly, M., Piqué, R. ,Terradas, X. 2017. Use of space and site formation processes in a Neolithic lakeside settlement. Pollen and non-pollen palynomorphs spatial analysis in La Draga (Banyoles, NE Iberia). *Journal of Archaeological Science* . 81, 101–115.

Revelles, J., Antolín, F., Berihuete, M., Buxó, R., Burjachs, F., Caruso, L., López, O., Palomo, A., Piqué, R., Terradas, X. 2014. Landscape transformation and economic practices among the first farming societies in Lake Banyoles

(Girona, Spain). *Environmental Archaeology* 19, 298–310.

Revelles, J., Cho, S., Iriarte, E., Burjachs, F., van Geelf, B., Palomo, A., Piqué, R., Peña-Chocarro, L., Terradas, X. 2015. Mid-Holocene vegetation history and Neolithic land-use in the Lake Banyoles area (Girona, Spain). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 435, 70–85.

Rheingold, H. 1993. *The virtual community: Finding commection in a computerized world*. Addison-Wesley Longman Publishing Co., Inc.

Rheingold, H. 1998. Comunidades virtuais. *DRUCKER, PF A comunidade do futuro: idéias para uma nova comunidade. São Paulo: Futura*, pp. 120-127.

Rheingold, H. 2016. 3 Daily Life in Cyberspace: How the Computerized Counterculture Built a New Kind of Place. *Social Media Archeology and Poetics*, 61.

Rij, T. van. 2005. *Constructieleer 1A - CT1052*, TU Delft.

Roberts, J. C. and Ryan, N. 1997. Alternative archaeological representations within virtual worlds. In *Proceedings of the 4th UK Virtual Reality Specialist Interest Group* Conference, pp. 179-188.

Robertson E.C., Seibert J, Fernandez D, Zender M. 2006. *Space and Spatial Analysis in Archaeology*. UNM Press, 2006.

Robin, C. and Rothschild, N.A. 2002. Archaeological ethnographies: Social dynamics of outdoor space. *Journal of Social Archaeology*, 2(2):159-172.

Rollefson, G. O. 2001. The Neolithic period. In *The archaeology of Jordan*, (Eds.). B. MacDonald, R. Adams and P. Bienkowski, 67–105. Sheffield: Sheffield Academic Press.

Rueda, N. A. and Escobar, J. A. 2017. Reconstruction of the lost Muisca Siecha raft pouring process by reverse engineering methodology. *Materials and Manufacturing Processes*, 32(7-8), 749-755.

Ruigrok, J. A.T. 2010. Laterally Loaded Piles Models and Measurements. Master Thesis. Delft University of Technologies.

Ruttkay, E. 1982. Archäologisches Fundmaterial aus den Stationen Abtsdorf I, Abtsdorf II und Weyregg I. *Fundberichte aus Osterreich* Horn, 21:19-23.

Ruttkay, E., Cichocki, O., Pernicka, E. and Pucher, E. 2004. Prehistoric lacustrine villages on the Austrian lakes. *Living on the lake in prehistoric Europe–150 years of lake-dwelling research*, edited by: Menotti, F. Routledge, London, pp.50-68.

Ryan, N.S. 2001. Documenting and validating virtual archaeology. *Archeologia e Calcolatori*, XII, pp.245-273.

Ryan, N.S., Frischer, B., Niccolucci, F., Barceló, J.A. 2002. From CVR to CVRO: the past, present, and future of cultural virtual reality. In: *Virtual Archaeology: Proceedings of the VAST Euroconference*, pp.7-18.

S

Sabbe, K. Serruys F. 2008. *Vakwerkstructuur als alternatieve fundering voor offshore windturbines*, KHBO, Oostende.

Sahabuddin, M.F.M. and Longo, C.G. 2015. Traditional values and their adaptation in social housing design: Towards a new typology and establishment of ‘Air House’standard in Malaysia. *International Journal of Architectural Research*. ArchNet-IJAR, 9(2), pp.31-44.

Sackett, J.R. 1985. Style and ethnicity in archaeology: the case for isochrestism. In *The Uses of Style in Archaeology*. M. Conkey, C. Hastorf (eds.), Cambridge University Press, pp.32-43.

Sales, A.M.P. 2013. Building in the Past: A Preliminary Analysis of the Construction Materials and Methods Used in Structure A in Barangay Pinagbayanan, San Juan, Batangas. *Hukay*, 18(1).

Sanders, D. 1990. Behavioural conventions and archaeology: methods for the analysis of ancient architecture. *Domestic architecture and the use of space*, 78:234.

Sanev, V. 1988. Neolitskoto svetilište od 'Tumba' vo Madjari. *Macedoniae Acta Archaeologica* 9:9–30.

Sanev, M. 1994. Mlado kameno vreme. *Arheolośka karta na Repblika Makedonija – Tom I*, 26–42. Skopje: MASA.

Scamozzi, V. (1997). 1615. *L'idea dell'architettura universale, Venice, Part, 2.*

Schambeau, M. E., Ramey, G. E., Hughes, M. L., Kang, J., Davidson, J. S. 2014. Screening tool to assess adequacy of bridge timber pile bents during extreme scour events. *Practice Periodical on Structural Design and Construction*, 19(3), 04014014-1.

Schirmer, W. 1990. Some aspects of building at the 'Aceramic-Neolithic' settlement of Çayönü Tepesi. *World Archaeology* 21:363–387.

Schlichtherle, H. 2004. Lake-dwellings in south-western Germany: history of research and contemporary perspectives. In Menotti F. (Ed.). 2004 *Living on the lake in prehistoric Europe: 150 years of lake-dwelling research*. pp. 22-36.

Routledge. London.

Schlichtherle, H. and Hohl, W. 2002. Fortschritte der Ausgrabung in der endneolithischen Moorsiedlung Torwiesen II in Bad Buchau am Federsee, Kreis Biberach, Baden-Württemberg. *NAU Nachrichtenblatt Arbeitskreis Unterwasserarchäologie*, 9:61-65.

Schneeberger, J. , Bollinger, J. , Buffie, N. and Yamazaki, K**.** 1983. Computerised three dimensional error analysis for automated part inspection. *Proc. llth North Am, Manuf. Res. Conf.*, Madison, WI, pp. 423-427

Schmidt, K. 1996. Nevali Çori: chronology and intrasite distribution of lithic tool classes: preliminary results. In *Neolithic chipped stone industries of the Fertile Crescent, and their contemporaries in adjacent region*, (Eds). S. K. Kosłowski and H.-G. K. Gebel, 363–376. Berlin: ex oriente.

Selirand, J. 1985. On underwater archaeology in Sowiet-Estonia. – *Seafaring on the Baltic in the 18th Century: Publication of the Provincial Museum of Kymenlaakso*, 4:32–46. Kotka.

Shelley, C. 1996. Visual abductive reasoning in archaeology. *Philosophy of Science*, 63(2), 278-301.

Shelley, C. 1999. Multiple analogies in archaeology. *Philosophy of Science*, 66(4):579-605.

Sherratt, A. 2004. The importance of lake-dwellings in European prehistory. *Living on the lake in prehistoric Europe*, 150:267-75.

Sifniotis, M., Jackson, B., White, M., Mania, K. and Watten, P. 2006. Visualising uncertainty in archaeological reconstructions: a possibilistic approach. In *ACM SIGGRAPH 2006 Sketches* (p. 160). ACM.

Sifniotis, M., Jackson, B., Mania, K., Vlassis, N., Watten, P. L. and White, M. 2010. 3D visualization of archaeological uncertainty. In *Proceedings of the 7th Symposium on Applied Perception in Graphics and Visualization* (pp. 162-162). ACM.

Silberman, N. A. 2007. The Ename Charter: the first draft. *Interpreting the past*, 2:223-247.

Silberman, N. A. 2009. Process not product: the ICOMOS Ename Charter (2008) and the practice of heritage stewardship. *CRM: The Journal of Heritage Stewardship*, 7.

Simoska, D. 1986. Veluška Tumba: Neolitska naselba. *Arheološki Pregled* 26:48.

Simoska, D. and V. Sanev. 1975. Neolitska naselba Veluśka tumba kaj Bitola. *Macedoniae Acta Archaeologica* 1:25–85.

Simmons, A. H. and Najjar, M. 2003. Ghuwayr I, a Pre-Pottery Neolithic B settlement in southern Jordan: report of the 1996–2000 campaigns. *Annual of the Department of Antiquities of Jordan* 47:407–430.

Simms, S.R. 1992. Ethnoarchaeology: Obnoxious spectator, trivial pursuit, or the keys to a time machine? In Wandsnider, L. (Ed.), *Quandaries and Quests: Visions of Archaeology's Future*, Southern Illinois University, Center for Archaeological Investigations, Occasional Paper No. 20, pp. 186–198.

Sims, D. 1997. Archaeological models: pretty pictures or research tools? *IEEE Computer Graphics*, 17 (1): 13-15.

Skibo, J. 2009. Archaeological theory and snake-oil peddling: The role of ethnoarchaeology in archaeology. *Ethnoarchaeology*, 1(1):27-56.

Sommer, U. 2001. ‘Hear the instruction of thy father, and forsake not the law of thy mother’: change and persistence in the European early Neolithic. *Journal of Social Archaeology* 1: 244–270.

Souvatzi, S. 2013. *Diversity, Uniformity and the Transformative Properties of the House in Neolithic Greece*. In D. Hofmann, J. Smyth (Eds.), Tracking the Neolithic House in Europe, One World Archaeology. Pp. 45-64. Springer, New York.

Srivastava, S., Kumar, R. and Singh, V. P. 2013. *Wood Decaying Fungi*. LAP LAMBERT Academic Publishing.

Stahl, A.B. 1993. Concepts of time and approaches to archaeological reasoning in historical perspective. *American Antiquity*, 58:235–260.

St. Amant, R. 2002. *A Preliminary Discussion of Tools and Tool Use*. NCSU Technical Report TR-2002-06.

Stanco, F. and Tanasi, D. 2013. Beyond virtual replicas: 3D modeling and maltese prehistoric architecture. *Journal of Electrical and Computer engineering*, 11.

Stanislawski, M.B. 1969. The ethno-archaeology of Hopi pottery making. *Plateau*, 42(1):27-33.

Stanislawski, M.B. 1977. Ethnoarchaeology of Hopi and Hopi-Tewa pottery making: Styles of learning. *Experimental archaeology*, pp. 378-408.

Stanislawski, M.B. 1978. If pots were mortal. In R. Gould (Ed.), *Explorations in Ethnoarchaeology*. Albuquerque: University of New Mexico Press, pp. 201-

227.

Stäuble, H. and Lüning, J. 1999. Phosphatanalysen in bandkeramischen Häusern.
Archäologisches Korrespondenzblatt 29:169–187.

Steadman, P. 2006. Why are most buildings rectangular? *Arq: Architectural Research Quarterly*, 10(2):119-130.

Steadman, S. R. 1996. Recent research in the archaeology of architecture: Beyond the foundations. *Journal of Archaeological Research*, 4(1):51-93.

Stekelis, M. and T. Yisraely. 1963. Excavations at Nahal Oren: preliminary report. *Israel Exploration Journal* 13:1–12.

Steward, J.H. 1942. The direct historical approach to archaeology. *American Antiquity*, 7:337–343.

Stiles, D. 1977. "Ethnoarchaeology: A Discussion of Methods and Applications". *Man* 12 (1): 87–101.

Stowers, J. R., Fuhrmann, A., Hofbauer, M., Streinzer, M., Schmid, A., Dickinson, M. H. and Straw, A. D. 2014. Reverse engineering animal vision with virtual reality and genetics. *Computer, 47*(7):38-45.

Strothotte, T., Puhle, M., Masuch, M., Freudenberg, B., Kreiker, S. and Ludowici, B. 1999a. Visualizing uncertainty in virtual reconstructions. *Proc. EVA Europe*, 16.

Strothotte, T., Masuch, M. and Isenberg, T. 1999b. Visualizing Knowledge about Virtual Reconstructions of Ancient Architecture. In *Computer Graphics International*, pp. 36-43.

T

Tarrus, J., Aliaga, S., Chinchilla, J. and Mercadal O. 2016. Ca nIsach (Palau-saverdera): un poblado neolítico (V-IV milenio aC) en la zona dolménica del Alt Empordà. In *Del neolític a l'edat de bronze en el Meditarrani occidental: estudis en homenatge a Bernat Martí Oliver*, pp. 249-256.

Tarrus, J. 2008. La Draga (Banyoles, Catalunya), un poblat lacustre del neolític antic a l'Europa mediterrània. *Catalan Historical Review*, 1:171-182.

Temelkoski, D. and A. Mitkoski. 2006. Praistoriska naselba Mogila Senokos. *Macedoniae Acta Archaeologica* 17:55–88.

Tepavčević, B. and Stojaković, V. 2013. Procedural modeling in architecture based on statistical and fuzzy inference. *Automation in Construction*, *35*:329-337.

Theunissen, E.M., Brinkkemper, O., Lauwerier, R.C.G.M., Smit, B.I. and I.M.M.Van.Der.Jagt (eds.) 2014. A Mosaic of habitation at Zeewijk (the Netherlands). Late Neolithic Behavioural Variability in a Dynamic Landscape. In *Nederlandse Archeologische Rapporten*, 47.

Thompson, R. H. 1958. Modern Yucatecan Maya Pottery Making. *Memoirs of the Society for American Archaeology*, (15):1-157.

Tite, M.S., Kilikoglou, V. and Vekinis, G. 2001. Review article: ´Strength, toughness and thermal shock resistance of ancient ceramics, and their influence on technological choice’. *Archaeometry* 43(3):301–24.

Tjahjono, G. 2003. Reviving the Betawi Tradition: The Case of Setu Babakan, Indonesia. *Traditional Dwellings and Settlements Review*, pp.59-71.

Tolevski, I. 2009. Architecture. In *Neolithic communities in the Republic of Macedonia*, (Eds.). G. Naumov, Lj. Fidanovski, I. Tolevski and A. Ivkovska, 37–44. Skopje, Dante.

Tomasi, G. 1982. *Le palafitte del Lago di Ledro*. Museo tridentino di scienze naturali.

Tomlinson, M. and Woodward, J. 2014. *Pile design and construction practice*. CRC Press.

Toufexis, G. 1996. House models. In *Neolithic culture in Greece*, ed. G. Papathanassopoulos, 161–162. Athens, Goulandris Foundation.

Toufexis, G. and E. Skafida. 1998. *Neolithic house models from Thessaly, Greece. International Union of Prehistoric and Protohistoric Sciences, XIII Congress Proceedings*, (Eds.). C. Pereto and C. Giunchi, 339–346. Forlì: A.B.BCO. Edizioni.

Touloumis, K. and Hourmouziadi, A. 2003. The Man and the Lake: Living in the Neolithic Lakeside Settlement of Dispilio, Kastoria, Greece. *Mediterranean Archaeology and Archaeometry*, 3(2):13-79.

Trigger, B.G. 1989. *A History of Archaeological Thought*, Cambridge University Press, Cambridge.

Tsuji, S. 1999. Koseido 14C nendai sokutei ni yoru Sannai Maruyama Iseki no hennen. (Chronology at the Sannai Maruyama site using a high precision 14C dating method). *Gekkan Chikyu Special Issue* 26:32-38.

Turkle, S. 1996. Working on Identity in Virtual Space. *Constructing the self in a mediated world*, 156.

Turkle, S. 1997. Multiple subjectivity and virtual community at the end of the Freudian century. *Sociological inquiry*, *67*(1):72-84.

Turkle, S. 2005. *The second self: Computers and the human spirit*. MIT Press.

Turkle, S. 2016. *Reclaiming conversation: The power of talk in a digital age*. Penguin.

U

USAITA – U.S. Army InFormAtIon technology Agency (n.a.). *Glossary*. U.S. Army Information Technology Agency. http://ita.army.mil/CatalogService.aspx?service_Id=122&serviceGroup_Id=9

V

Van Heeringen, R.M. and E.M. Theunissen 2001. Kwaliteitsbepalend onderzoek tenbehoeve van duurzaam behoud van neolithische terreinen in *WestFriesland en de Kop van NoordHolland, deel 2: site-dossiers, Amersfoort* (Nederlandse Archeologische Rapporten 21).

Van Nederveen, G. A. and Tolman, F. P. 1992. Modelling multiple views on buildings. *Automation in Construction*, 1(3):215-224.

Várady, T., Martin, R. R. and Cox, J. 1997. Reverse engineering of geometric models. In *An Introduction, ComputerAided Design*.

Váradi, K., Palásti-Kovács, B., Czifra, Á., Néder, Z. and Kovács, K. 2004. 3D characterization of engineering surfaces. In *Budapest Tech Jubilee Conference*.
VERLAG, J.T. 2016. *4.000 Jahre Pfahlbauten*. Baden-Württemberg, 2016.

Vasileva, M. 2005. *Kade e našeto minato. Voved kon praistorijata na Pelagonija*. Bitola, Visoi.

Veluscek, A. 2013. Datiranje arheološkega najdišča Maharski prekop na Ljubljanskem barju. *Arheološki vestnik*, 64:367-396.

Verlag, J.T. 2016. *4.000 Jahre Pfahlbauten*. Baden-Württemberg, 2016.

Vila, X. M. A., Rotea, R. B., Borrázas, P. M. 2003. *Archaeotecture: archaeology of architecture,* 1175. British Archaeological Reports Ltd.

Virtudes, A. and Almeida, F. 2012. The Territory Of "Avieiras" Stilt-House Villages In The Survey On Vernacular Architecture: What Does The Future Hold? In *Surveys of vernacular architecture: their significance in 20th century architectural culture, Conference Proceedings, (17-19 May 2012, Porto, Portugal)*, CEAA, ESAP (pp. 535-548).

Vischer, J. C. 2008. Towards a user-centred theory of the built environment. *Building research & information*, *36*(3):231-240.

Vogt, E. 1955. Pfahlbaustudien. In W.U. Guyan (Ed.). Das Pfahlbauproblem. Basel, Birkhäuser Verlag.

W

Waheeb, M. and N. Fino. 1997. 'Ayn el-Jammam: a Neolithic site near Ras en-Naqb, southern Jordan. In *The prehistory of Jordan, II. Perspectives from 1997*, (Eds). H.-G. K. Gebel, Z. Kafafi and G. O. Rollefson, 215–220. Berlin, Ex Oriente.

Wang, W. 2011. *Reverse Engineering: Technology of Reinvention*. CRC Press, Boca Ratón (FL).

Waterbolk, H.T., Van Zeist, W. 1991. Niederwil, eine Siedlung der Pfyner Kultur. *Academica Helvetica* 1. Bern, Stuttgart.

Waterbolk, H.T., Van Zeist, W. 1978. *Niederwil, Eine Siedlung der Pfyner Kultur, Academia Helvetica, Haupt, Bern, Bd 1, Die Grabungen, Bd 2, Beilagen*.

Watson, P.J. 1979a. The idea of ethnoarchaeology: notes and comments. *Ethnoarchaeology: Implications of Ethnography for Archaeology*, Columbia University Press, New York, pp. 277-287.

Watson, P. J. 1979b. *Archaeological ethnography in western Iran*. University of Arizona Press.

Wedel, W.R. 1938. "The Direct-Historical Approach in Pawnee Archaeology." *Smithsonian Miscellaneous Collections* 97(7): 1–21

Whittle, A. W. R. 1996. *Europe in the Neolithic. The Creation of New Worlds*. Cambridge, Cambridge University Press.

Whittle, A. W. R. 2003. *The Archaeology of People*. *Dimensions of Neolithic Life*. London, Routledge.

Whittle, A. W. R. 2009. The Neolithic Period, c. 4000-2400 cal BC: a changing world. In: Hunter, J. and Ralston, I. (Eds.). *The Archaeology of Britain: An Introduction from Earliest Times to the Twenty-First Century.* 2nd ed. London, Routledge, pp. 78-102.

Wiessner, P. 1983. Style and social information in Kalahari San projectile points. *American Antiquity,* 48:253-276.

Wiessner, P. 1989. Style and Changing Relations Between the Individual and

Society. In *The Meanings of Things: Material Cultural and Symbolic Expression*. I. Hodder (Ed.), Unwin Hyman, London.

Wilk, R. R. (Ed.) 1989a. *The Household Economy: Reconsidering the Domestic Mode of Production*. Westview Press, San Francisco.

Wilk, R. R. 1989b. Decision making and resource flows within the household: Beyond the black box. In Wilk, R. R. (Ed.). *The Household Economy: Reconsidering the Domestic Mode of Production*. Westview Press, San Francisco, pp: 23–54.

Wilkes, J. A. and Packard, R. T. 1990. *Encyclopedia of architecture: design, engineering & construction*. Wiley.

Willey, G.R. 1953. What archaeologists want? In Tax, S., Eisley, L. C., Rouse, I., and Voegelin, C. F. (Eds.), *An Appraisal of Anthropology Today*, University of Chicago Press, Chicago, pp. 229–230.

Wobst, H.M. 1977. Stylistic Behaviour and Information Exchange. In *For the Director: Research Essays in Honor of James B. Griffen.*, E.H. Cleland (Ed.), University of Michigan Museum of Anthropology, Anthropological Papers, Ann Arbour, pp.317-342.

Wobst, H. M. 1978. The archaeo-ethnology of hunter–gatherers or the tyranny of the ethnographic record in archaeology. *American Antiquity*, 43:303–309.

Woodwark, J. 1991. Reconstructing history with computer graphics. *IEEE Computer Graphics and Applications*, 11(1):18-20.

Wright, L. 1973. Functions. *Philosophical Review*, 82:139-68.

Wylie, A. 1982. An analogy by any other name is just as analogical: A commentary on the Gould–Watson dialogue. *Journal of Anthropological Archaeology*, 1:382–401.

Wylie, A. 1985. The reaction against analogy. In *Advances in Archaeological Method and Theory*, Volume 8 (pp. 63-111).

Wylie, A. 1988. “Simple” analogy and the role of relevance assumptions: Implications of archaeological practice. *International Studies in the Philosophy of Science*, 2:134–150.

Wylie, A. 1989. Archaeological cables and tacking: The implications of practice for Bernstein's “Options beyond objectivism and relativism.” *Philosophy of Social Science*, 19:1–18.

X

Xia, Z. 2014. Application of reverse engineering based on computer in product design. *International Journal of Multimedia and Ubiquitous Engineering*, *9*(5):343-354.

Y

Yellen, J. E. 1977. *Archaeological approaches to the present: models for reconstructing the past* (Vol. 1). Academic Press.

Yuan, L.J. 2001. The traditional Malay house. *United Nations Development Programme, Special Unit for Technical Cooperation among Developing Countries, Sharing Innovative Experiences,* 2.

Yuan, L.J. 1987. *The Malay House: Rediscovering Malaysia's Indigenous Shelter System*. Pulau Pinang, Institut Masyaraket. Pp. 152.

Z

Zadeh, L. A. 1996. Fuzzy sets. In *Fuzzy Sets, Fuzzy Logic, And Fuzzy Systems: Selected Papers by Lotfi A Zadeh*, pp: 394-432.

Zanini, A. (Ed.). 1997. *Dal bronzo al ferro: il II millennio aC nella Toscana centro occidentale;[22 novembre 1997-31 maggio 1998, Livorno, Museo di Storia Naturale del Mediterraneo]*. Pacini.

Zdravkovski, D. 1990. Načinot na gradenje na neolitskite kući. *Kulturno nasledstvo* 14/15:75–80.

Zheng, Y. F. and Jiang, L. 2007. Remains of ancient rice unearthed from the Shangshan site and their significance. *Archaeology*, 9:19-25.

Zuk, T., Carpendale, M. S. T. and Glanzman, W. D. 2005. Visualizing Temporal Uncertainty in 3D Virtual Reconstructions. In *VAST* 2005, p. 6th).