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REVISION OF THE PAST

- Constructing ancient long houses in the 21st century -

Creative Media and Game Technologies,
Saxion University of Applied Sciences

1. Acknowledgements

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3. Glossary

Game-engine	<i>Game's software engine, it executes the core functionality of the game.</i>
Influence Diagram	<i>For a model to be effective in helping a client make better decisions, the client has to trust that it is a good representation of the problem -- the way the decisions, assumptions, and uncertainties affect the objectives that they care about. It is therefore important that the model be transparent -- that the modeler and others, including the client, can understand the essential structure and assumptions, so that they can develop confidence in the results. A simple influence diagram depicts a variable describing the situation: a decision – What do we do? a chance variable – What's the outcome? a final valuation – How do we like it? (Clemen, 1996)</i>
Longhouse	<i>A longhouse or long house is a type of long, narrow, single room building built by peoples in various parts of the world. Many were built from timber and represent the earliest form of permanent structure in many cultures. (Tanabe, 2018)</i>
Granary	<i>Wooden, brick, or stone-built structure used for storing grain or other crops built on stilts or legs of some kind to raise it off the ground. (Darvill, 2008)</i>
Housing plan	<i>A configuration of surviving remains that we interpret as coming from a house and that is presented graphically with a view from above. (Huijbers, 2007)</i>

- Posthole** *Small manmade pit visible as a smudge on the surface of an archaeological deposit, where a wooden post has once been pushed into the ground surface. (Darvill, 2008)*
- Excavation** *One of the principal means by which archaeological data is captured and recorded, excavation involves the systematic exposure of deposits that are then taken apart. (Darvill, 2008)*
- Scientifically accurate** *Testing a theory against further observations made in a way that is replicable. Many archaeologists wish to adhere to such a method to ensure objectivity in their work. (Darvill, 2008)*

4. Introduction

“Scientific visualization of archeology is getting more important in the age of digitalization, this is more coherent to the digitization of the world around us, rather than any systematic and strategic implementation of method and approaches” (Zubrow, 2006), meaning that the world around archeology is digitizing quickly and that archaeology has to do the same to not fall behind. As a result, archaeology must keep up to date on ways to visualize findings. The visualizations of these findings should be visually pleasing, but also add scientific value. This thesis expands on existing technologies and how these can be used to gain benefits and stay up to date with modern world standards, as shown by Fieldhouse (2020) and Georgopoulos (2013). TijdLab visualizes house plans on a regular basis, this is an expensive and time-consuming process. It is of utmost importance that all sources are consulted and are traceable in this visualization. To create a more durable workflow, we must dive inside the current workflow(s) that are being used by the company and new external workflows, how these (new) workflows can be expanded and/or further discovered and improved.

We will go through a few standard methods and their respective software and rate them based on criteria. We will use the chosen method(s) to create a workflow for the company, this workflow will visualize and describe the steps that are needed to solve this problem.

4.1. Company Outline

TijdLab is a company founded in 2015, located in Deventer. The company consists of five employees, two archeologists, one GIS-specialist, and two 3D artists. The company creates tailor made, innovative solutions for home and abroad ("TijdLab", 2017), and it is focused in bringing history/archeology to life by visualizations and developing/investing in new technologies. With these technologies TijdLab creates bridges between past, present, and future. TijdLab makes these connections available through interactive (3D) presentations, (3D) content, and GIS-solutions. This content includes hologram cabinets, touch tables, 3D printing, VR, AR, gamification, and others. The company tries to make 3D content as scientifically accurate as possible, by using important data available and their archaeological knowledge to fill in data that is not complete.



Figure 1 Bronze Torque from the Iron Age

5. Problem Analysis

5.1. Reason and demands of TijdLab

Currently TijdLab is mostly relying on more traditional methods of creating 3D models but the company wants to test existing and new workflows and discover which workflow specifically enables the creation of 3D longhouses. A geometric 3D model of a longhouse has been made by the company following a traditional workflow, but there is no workflow to convert all the 2D longhouse data (Waterbolk, 2009) into 3D geometry, being efficient and scientifically accurate. The reason for the company to request a workflow is that the company as well as the client needs to invest a vast amount of money every single time longhouses need to be digitally re-constructed in 3D and this affects the company financially. TijdLab wants a workflow that will solve this problem, this workflow will include a visualization of steps and an accurate description, this workflow being more efficient than the current traditional workflow. An efficient workflow has three key features; 1. it increases speed, 2. it decreases mistakes, 3. it increases return of investment ("How to Improve Workflow," n.d.). To gain these key features a workflow must be defined and tested.

6. Reason for the assignment

6.1. General description of assignment

TijdLab is looking for ways to make the modeling process more efficient. The goal of this thesis is to solve this, which enables TijdLab to use 2D housing plans to model and re-construct archaeological accurate longhouses by using 2D housing plans. These 2D housing plans emerge from research that have been done on excavation sites and depict findings from archaeologists. This process will be displayed in a way that users with experience in 3D software can follow the steps and get a consistent and re-producible result, specifically regarding longhouses. In the test-case, Heeten, this workflow will be used to create a granary for a village in Heeten that existed around 300 A.C. Heeten is a small town near Raalte in the region of Salland. There has been archeological research undertaken by “ADC ArcheoProjecten” from Amersfoort and “Rijksdienst voor het Cultureelerfgoed” (RCE). This research shows evidence of a Germanic farmer’s community living here in the Roman time (753 B.C. till 476 A.D.), around 300 A.C, that traded iron with the Romans (Verlinde, Toebosch, 1993). In these research 2D excavation maps were created that will be used to create a workflow where data input is the foundation of a 3D model.

6.2. Stakeholders

TijdLab is the main stakeholder for this research. Tijdlab is expected to benefit from this research by using the to be created workflow. Stichting Germanen Heeten is the second stakeholder, and Stichting Duiven the third stakeholder. Stichting Germanen Heeten and Stichting Duiven contribute with information and thus have future interest that could lead into further investments into TijdLab. Both are ongoing processes with limited budgets that have a large amount of housing plans that needs to be visualized in 3D by using excavation data.

6.3. Scope & Limitations

This thesis tries to tackle problems the company faces by giving new approaches to workflows. There is a lack of studies in workflows for modeling archaeological scientifically accurate models in an efficient way. It is a specific problem and non-traditional model workflows are a recent phenomenon in the archaeological industry. To broaden the view, more research from other fields, such as gaming and other visualization industries, will be taken in consideration to lay the foundations of a new workflow. There are different tools available, but this thesis will mainly focus on the tools that are or have been used by the company: Maya, Houdini, and Reality Capture. The costs for the thesis are not an important factor because it is expected to not cost more than the labor of the researcher. A base groundwork for a workflow will be made during this thesis, but not an exhaustive research of every tool and method available, it will be a comprehensive review of tools and theory.

Finding a method and workflow to convert 2D house plans to 3D geometry is the main goal of this thesis. This includes a theoretical framework behind choosing a suitable method and software that takes in consideration different internal and external factors. Furthermore, after the method and software determination this thesis will work out a workflow to create 3D models from excavation maps.

6.4. Problem Definition

There are many different 2D housing plans available from excavations (Waterbolk, 2009), as can be seen in figure 2. The problem is that there is not a sustainable method to convert the data from these 2D plans into 3D geometry in an efficient and scientifically accurate way.

The company wants to create an efficient, scientifically accurate and commercially viable workflow to tackle this problem and use this workflow to create visually interesting but scientifically accurate longhouses.

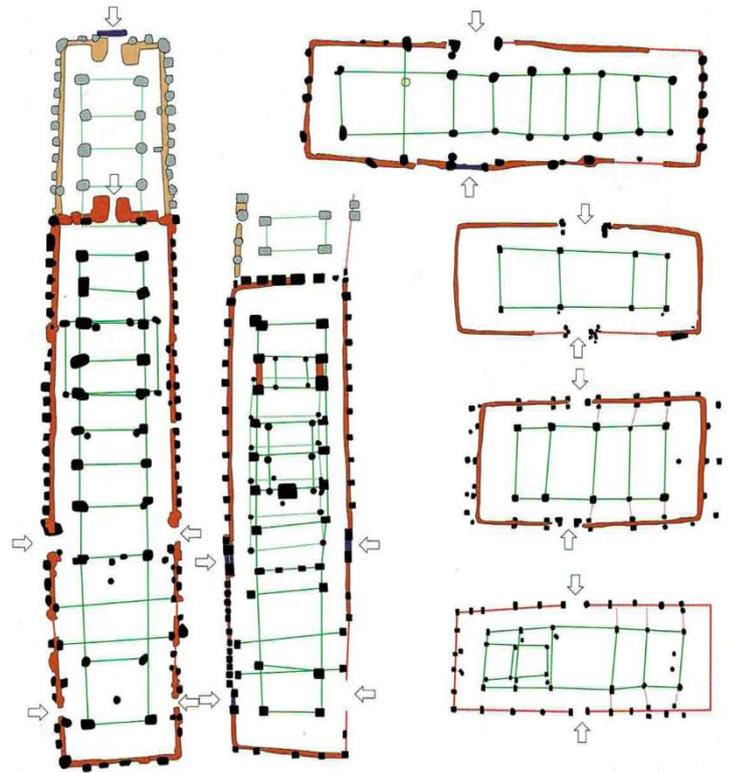


Figure 2 'Getimmerd Verleden' Housing plan (Waterbolk, 2009)

6.5. Research question

Considering the demands of TijdLab in addition with the problem analysis and problem definition research questions emerge. These questions are formed to be measurable, achievable, relevant/realistic, and time-bound, abbreviated as SMART.

6.5.1. Main question:

What is the ideal workflow for creating 3D models of longhouses that is reproducible, efficient, and applicable for different 2D house plans?

6.5.2. Sub questions:

- 1) What methods are available and reproducible to model a longhouse from a 2D house plan that is implementable in the to be created workflow?
- 2) How are the available and useable workflow(s) applicable in a 3D model scenario and what do these workflows look like?
- 3) In what way is it possible to prevent uncertainties in data from detracting the scientific relevance of a 3D model or making it impossible to create a relevant 3D model?
- 4) In what way can this workflow be used to make products that create commercial value?

7. Software and method determination

To determine what the best method is to succeed in creating these longhouses we first need to determine what methods are generally used. There are generally three different methods to create scientifically accurate 3D models such as Photogrammetry/scanning, direct modeling, and parametric modeling (Stanco, Battiato, & Gallo, 2017; Campana, 2014; Dore & Murphy, 2013). These methods can be used together in harmony. TijdLab already has certain software licenses ongoing so we will use the methods' respective software that is already being used in TijdLab. For photogrammetry that is Reality Capture, for direct modeling it is Maya, and for parametric modeling Houdini FX is used. There are other aspects of these methods like Substance Painter for texturing, this program is used in TijdLab but will not be included in the analysis because this thesis is mostly focused on increasing the modelling workflow. The Weighted Scoring model (Famuyide, 2014) will be used to compare the three methods to find which one would work best for the company.

7.1. Methods

7.1.1. Photogrammetry

Photogrammetry forms textured 3D meshes from data that is generated from systematic series of photographs and can be used for small and large objects (Fieldhouse, 2019). There are three types of photogrammetry, namely, **Aerial photogrammetry** (from airspace), **terrestrial photogrammetry** (from a handheld device), and **nautical photogrammetry** (under water). For large objects Aerial is the type to go for (Aber, Marzloff, & Ries, 2010).

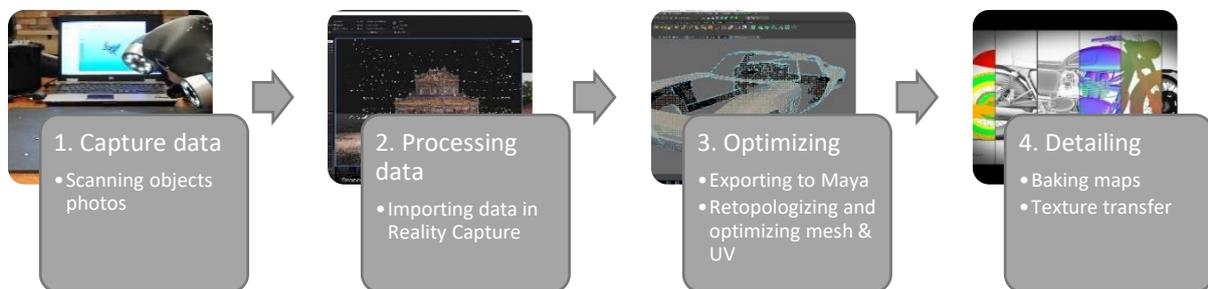


Figure 3 Reality Capture workflow

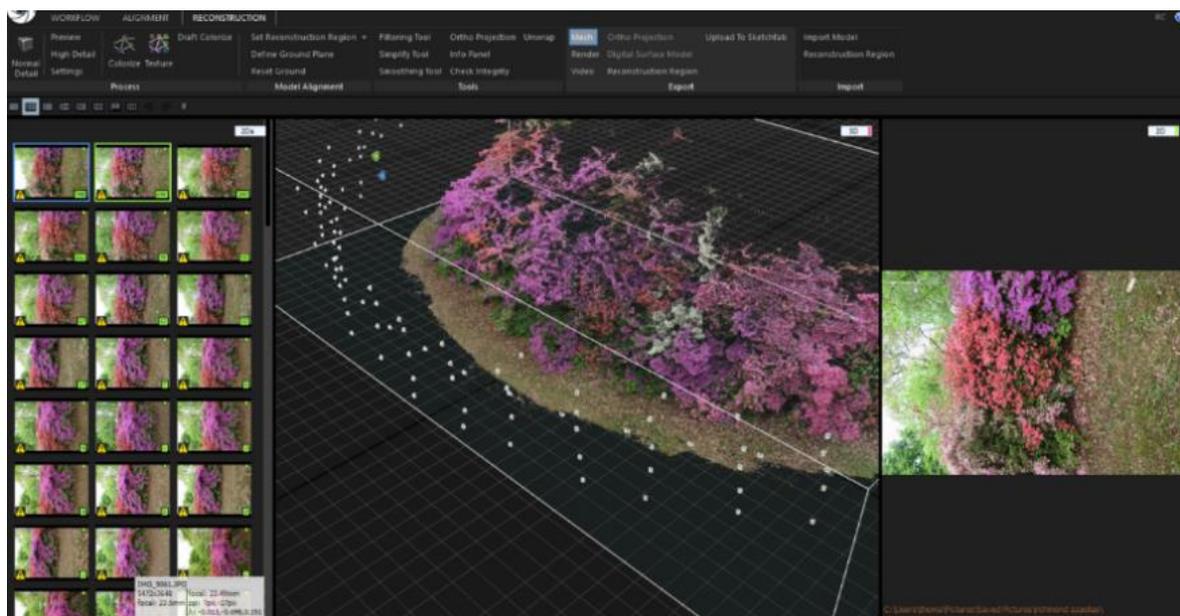


Figure 4 Reality Capture viewport and UI

7.1.2. Direct modeling

Direct modeling is the most traditional way of modeling. To create, interact and change a mesh the user can directly manipulate the model from within the viewport. This is an effective method to quickly generate ideas and designs. (Shapr3D, 2020)

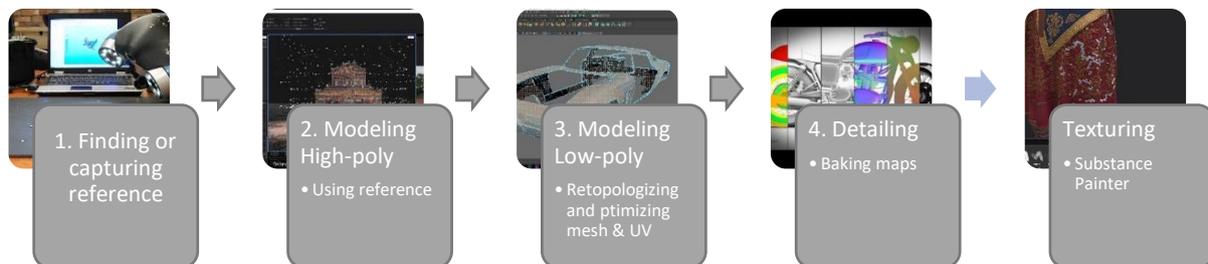


Figure 5 Direct modeling Workflow

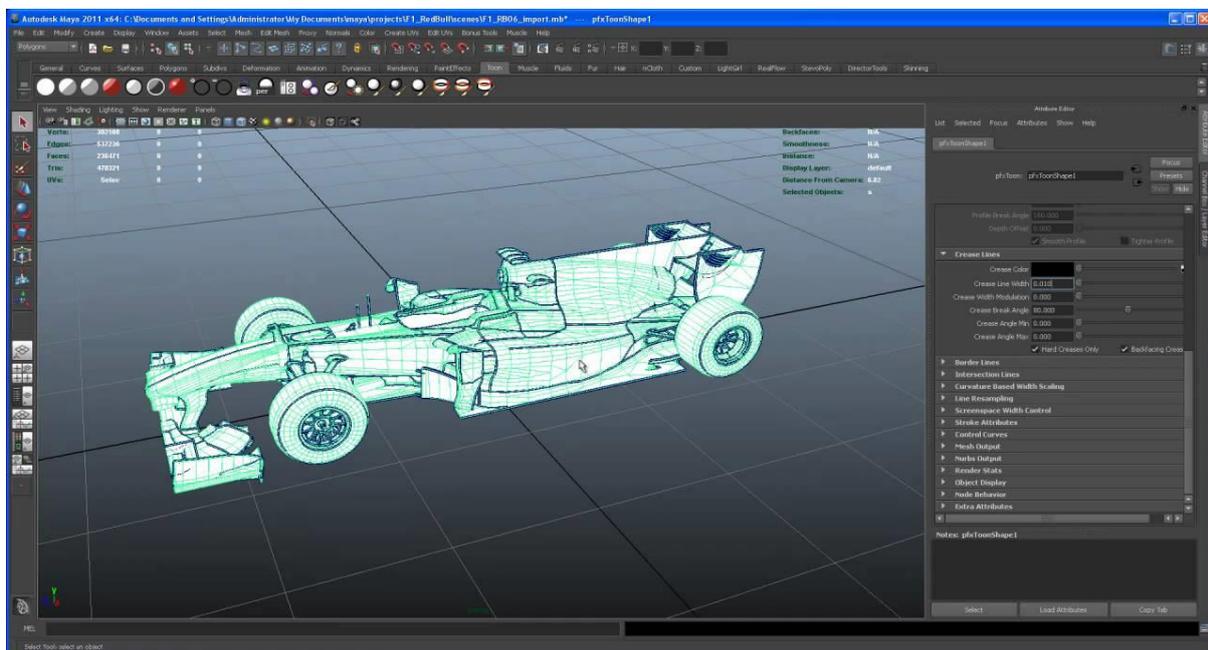


Figure 6 Maya viewport and UI

7.1.3. Parametric modeling

Parametric modeling uses a non-history based system so a user can change any of these steps previously taken to affect the entire process. This process can contain a multitude of parameters that can generate a multitude of different outputs. ("Houdini (software)", 2020)

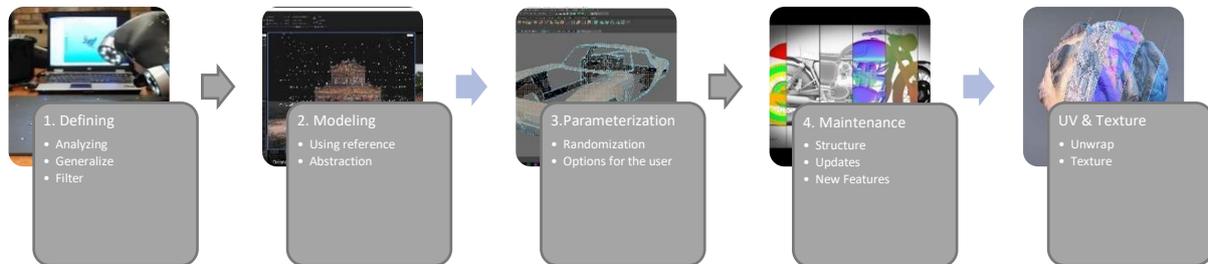


Figure 7 Parametric modeling workflow

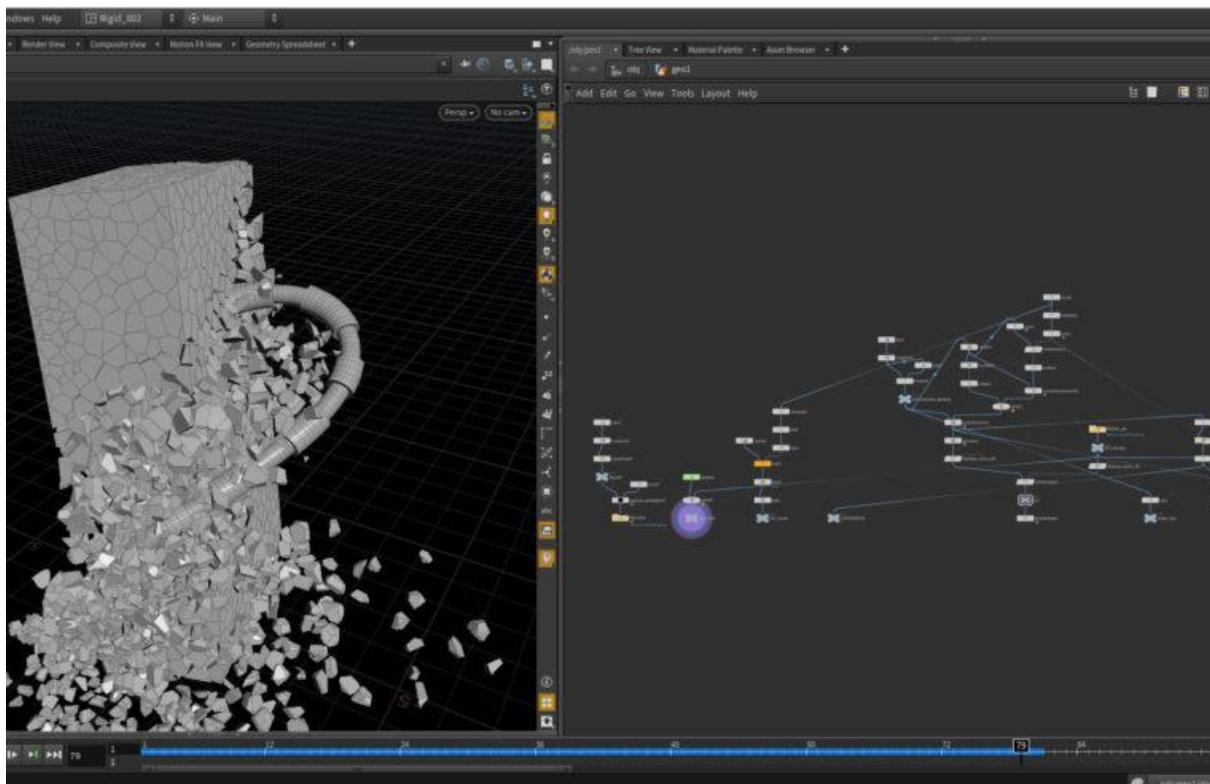


Figure 8 Houdini scene viewport and network viewport

8. The weighted scoring model

This model uses criteria to analyze and measure methods to output quantitative data from where a decision can be made to use a certain method. This model consists of three stages; 1. Identifying the requirements, 2. ranking each software options based on criteria, 3. assign scores to each software selected. There are several criteria and sub-criteria that are used to quantify the outcomes to find the most effective method, mostly based on research and testing. The method photogrammetry is not feasible for this project due to the lack of physical longhouses, therefore this method is not achievable. Nevertheless, this method is included in this scoring model so TijdLab can use it in future research. Requirements for both the artists' and company's' needs are weighted equally. For the artists, the criteria will be kept towards the artists' side: flexibility, ease of use etc. The company's' criteria will be more focused on the question of archaeological and commercial purposes: replicability/reproducibility, cost per project, and sustainability workflow/software. This is done to make sure all relevant stakeholders are represented. Each criterion will include a brief software analysis (appendix) and quantification in sub-criteria, quantification is done with grades from 1 which is very bad to 5 which is very good.

8.1. Criteria and outcomes

8.1.1. Perceived ease of use

Ease of use is defined as the degree to which the user believes that using the system will be free from effort. Ease of use is in direct connection with the usefulness, meaning if two systems offer identical functionality, the user that finds the software that is easier to use more useful. (Morris, Dillon, 1997). We will use this information described by Morris and Dillon to quantify the ease of use of each program.

8.1.1.1. Analysis

Maya is a direct model tool, so almost everything that can be done is also done directly inside the viewport which makes the ease of use higher. If a person has worked with similar software it makes the perceived ease of use higher. **Houdini** is mostly non-direct modeling, it is node-based, the process that takes place in expressions and functions, this makes Houdini less intuitive. **Reality Capture**' UI is a-like Microsoft Word. This makes the perceived of use already higher, as well as the workflow itself is very straightforward and linear, which makes working with it satisfying and efficient.

8.1.1.2. Quantification in sub-criteria

	Houdini FX	Maya	Reality Capture
Learnability	2	3	5
Documentation	5	4	3
Efficiency	2	3	5
Satisfaction	1	2	5
Memorability	3	4	5
Average	2.60	3.20	4.60

Table 1 Perceived ease of use

8.1.2. Flexibility

Unifying the definitions of flexibility by research is a big challenge. Papers define flexibility as enigmatic (Davis, 2013) and is often misconceived as an absolute quality (Eden & Mens, 2006). Thus, to be able to measure the flexibility of 3D modeling software we formulate a definition. We define the flexibility of a 3D modeling program as the ability to modify a scene without major re-design. For example, if a user creates a cylinder and bends it, but later in the process wants to have a torus instead of the cylinder, how much effort does a user need to take to replace the cylinder with the torus and get the same bend.

8.1.2.1. Analysis

Maya is less flexible, inherently to the design of the program it is not intended to go back inside the mesh history and change aspects of the model there, because it will break other parts of the model. **Houdini** is more flexible, any changes can be made whenever, because the network editor has a full use-friendly list of all actions that are made. **Reality capture** is not flexible at all, it is a linear workflow that has little options to execute manual actions.

8.1.2.2. Quantification in sub-criteria

	Houdini FX	Maya	Reality Capture
Adaptability	5	5	1
Plugins/Addons	5	5	2
UI modifications	4	5	1
Stability	5	2	4
Average	4.75	4.25	1.75

Table 2 Flexibility

8.1.3. Iterative capability

Iterations are a repetition of the same 3D model but slightly different. The iterative capability of a 3D program is defined by the ease of a process to generate a sequence of outcomes or in this case, meshes. The idea behind this is that it is generated by the computer that execute a procedure. Parameters are added to this process so that artists and designers can influence the product and control the design process (Hendrikx, Meijer, Velden, & Iosup, 2013). This iterative capability is an important factor to know because it could greatly reduce the amount of work, and thus, costs.

8.1.3.1. Analysis

Houdini has a node-based workflow that makes it easy for the user to create parameters to generate iterations of work. **Maya** has some plugins that offer iterative capability, but the program itself is not designed for this. **Reality Capture** relies on images that are processed by the software and changes after this process are limited, this means it is not iterative.

8.1.3.2. Quantification in sub-criteria

	Houdini FX	Maya	Reality Capture
Built in parameters	5	5	3
Flexible creation process	5	4	2
Custom parameters	4	4	1
Average	4.66	4.33	1.66

Table 3 Iterative Capability

8.1.4. Quality output related to low-end devices

This criterion is two metrics in one, meaning that both parts of the criterion, the output quality and the low-end device requirement must be considered to define this criterion completely. Low-end devices require optimization of 3D meshes. So quality output related to low-end devices means the amount of optimization available whilst keeping the quality as high as possible. Normal baking is an important factor to include in this because it is widely used in game-engines to create detailing without actual geometry, and thus is better for performance. This criterion is important because the workflow will be used for a wide variety of devices and needs to be compatible.

8.1.4.1. Analysis

Maya and **Houdini** offer good quality output related to low-end devices. Both have an automated and manual optimization process available to optimize models. **Reality capture** has high quality output, but optimization for low-end devices is limited, the process is limited to reducing polygons automatically, this means any manual changes need to be done in an external program.

8.1.4.2. Quantification in sub-criteria

	Houdini FX	Maya	Reality Capture
Output Quality	5	5	5
Low-end optimization	4	5	1
Normal map baking	3	4	3
Average	4.00	4.67	3.00

Table 4 Quality output related to low-end devices

8.1.5. Reproducibility and replicability

Reproducibility is the ability to redo a specific process and get the same results with the original study using the same data (Leek, 2017). This is important so anyone can follow a workflow and get the same results. Replicability is the ability to redo a specific process and get ‘consistent’ results with the original study using new data (Leek, 2017). For this project it means that the process of converting a specific housing plan (data) to a 3D model (result) and can be rerun with a different housing plan and still have a “consistent” 3D model (result).

8.1.5.1. Analysis

Maya’s workflow makes the creation of models personal, which makes reproducing difficult. **Houdini** on the other hand has a clear list of logic operation the user used to shape a 3D model, making it easier to reproduce and replicate. **Reality Capture** reproducibility is impossible because the process is automated and every time it is executed the output can differ from before.

8.1.5.2. Quantification in sub-criteria

	Houdini FX	Maya	Reality Capture
Replicability	5	2	1
Reproducibility	5	3	3
Average	5.00	2.50	2.00

Table 5 Reproducibility and replicability

8.1.6. Sustainability workflow/software

The sustainability of workflows and software is linked through the whole chain of the workflow. Every chain consists of internal (program durability) and external factors (data durability, external software, and external expertise) that can affect the workflow and if a link is missing the whole chain could break. A sustainable workflow/program can be measured by the risk of failure when one of these links in the workflow chain is missing. Backwards-compatibility is also important for the sustainability of the software, opening old version files with newer versions.

8.1.6.1. Analysis

Houdini has a perpetual license plan, which means the company can invest once and keep using the same product with no further cost, except for an annual update. **Maya** and **Reality Capture** both have periodic licensing costs. In Maya the risk of failure missing chain is high because history gets deleted, unless a user saves versions incrementally. Houdini has a low risk of failure missing chain, because of the parametric workflow all steps can re-taken and if a function of the system fails it is identifiable quickly. Reality Capture is automated so if anything goes wrong the user has limited access to identify any problems.

8.1.6.2. Quantification in sub-criteria

	Houdini FX	Maya	Reality Capture
Risk of failure missing chain	4	3	1
Backwards-version compatibility	3	1	1
Program durability	3	3	3
Average	3.33	2.30	1.66

Table 6 Sustainability workflow/software

8.1.7. Cost per project

The cost per project is defined by direct/indirect costs and fixed/variable costs. Direct costs are labor, fixed costs is software licensing and hardware costs. To quantify costs per project is important for the company as they decide what software to use.

8.1.7.1. Analysis

Licensing is expensive, both for Houdini and Maya. Reality Capture is less expensive. Labor costs are also in favor of Reality Capture, photographing and processing takes less time than the modelling process in Maya or the parametric process in Houdini.

8.1.7.2. Quantification in sub-criteria

	Houdini FX	Maya	Reality Capture
Direct costs	1	2	4
Fixed costs	2	2	5
Average	1.50	2.00	4.50

Table 7 Cost per project

8.2. Conclusion method & software determination

As can be seen in figure 9, Houdini was found to be the most flexible, because of the workflow of the program it inherently creates a very flexible way of working. Every chain of the workflow is interchangeable and editable, this also means it scored high on iterative capabilities. Reproducibility and replicability are also high because every step a user takes can be re-taken in the same way. Maya has a higher perceived ease of use than Houdini, it is more interactive and direct modeling is a standard in the industry. Reality Capture has an even higher ease of use because of the automated process and the user interface. Both Maya and Houdini have features for direct modeling as well as parametric modeling, but Maya is better at the first and Houdini better at the latter. Therefore, it is recommended to use a combination of direct modeling and parametric modeling, that means using Houdini and Maya as software and create a workflow for this.

	Houdini FX	Maya	Reality Capture
1. Perceived Ease of use	2.60	3.20	4.60
2. Flexibility	4.75	4.25	1.75
3. Iterative Capability	4.66	4.33	1.66
4. Quality output related to low-end devices	4.00	4.67	3.00
5.Reproducibility and replicability	5.00	2.50	2.00
6. Sustainability workflow/software	3.33	2.30	1.33
7. Cost per project	1.50	2.00	4.50
Average	3.69	3.32	2.69

Table 8 Results weighted scoring model

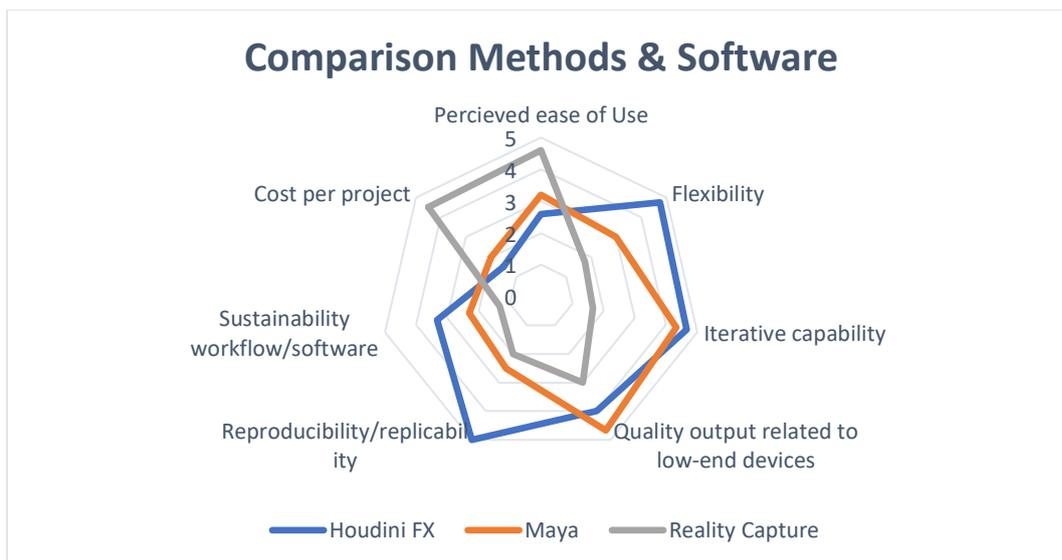


Figure 9 Comparison Methods & Software

9. Handling data uncertainties

The data that will be used can contain some uncertainties. These uncertainties are a lack of information. (Hansen, Chen, Johnson, Kaufman, & Hagen, 2014). For example, the data that is utilized in project Heeten consist of housing plans, that are generated from archaeological excavation findings. These findings are made by archeologists, who are forced to make assumptions when coming across uncertainties (Childe, 2018). These assumptions are called historical interpretation; more or less precise ideas of the properties and conditions in the past (Bentkowska-rafel, 2016). Thus, it is recommended archaeologist are consulted before continuing with a project if there are uncertainties in data, this to make sure everything is as scientifically accurate as possible. These consultations, to either colleague archaeologists or external archaeologists, should be documented so all data is verifiable and based on expertise of archaeologists. Another way of solving data uncertainties could be big data (Cooper and Green, 2015). This includes large and complex data to be used as a base to determine where uncertainties are and how to fill them in. This is a complex process that is not within the scope of this thesis nor in TijdLab present range of possibilities. If other fields or companies have significant progress in this process it is recommended that TijdLab takes a thorough look to see if it could be used for future project. But to address this topic on a scientific level is inherently too large as subject to include in this thesis.

10. What is a (good) workflow

Most direct 3D modelling workflows have a traditional setup based on rules of industry-wide best practices; finding/capturing references or concept art creation; 3D Modeling, unwrapping, texturing and baking (Treehouse, 2019; Turbosquid, 2019; Garner, 2020). The workflow for parametric modeling in Houdini is not linear, problems can be solved in many ways, which means that a general workflow must be thought out. The generalized workflow for Houdini I defined with my existing knowledge is: defining, modeling or importing, parameterization, unwrap, and maintenance. Proposing a new workflow requires defining, testing, and reiterating a workflow. Defining is a small explanation of what will be done in the step, testing will be done to see if problems arise in the step and reiterating is concluding based on the testing.

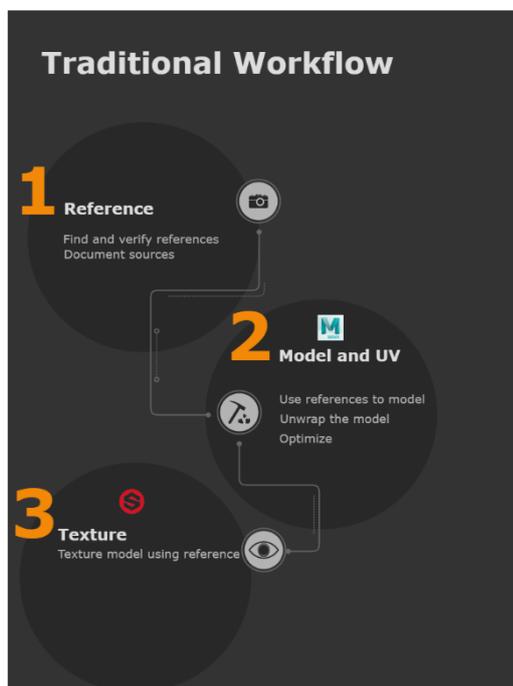


Figure 10 Traditional workflow

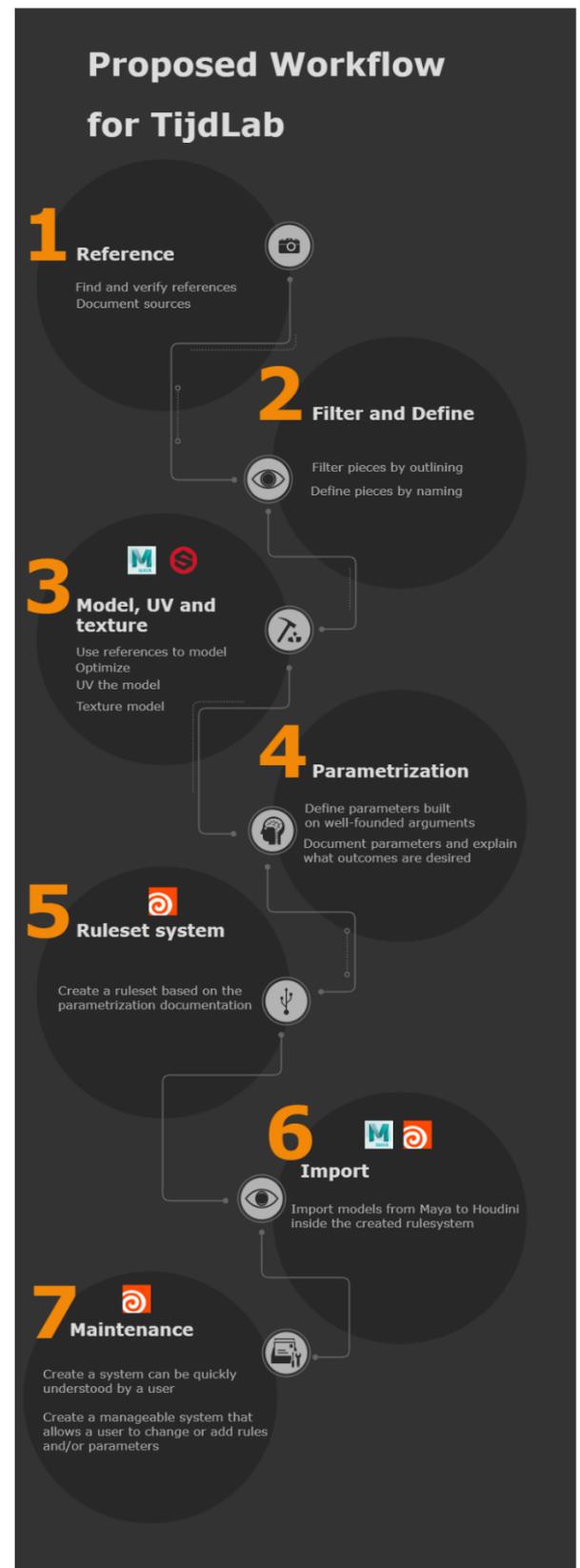


Figure 11 Proposed workflow

10.1. Traditional workflow

10.1.1. Reference

As seen in figure 11 references must be found and verified. These references can include images, documentation, video material, etc. All these resources will help with the modeling process and contribute to the scientific accurateness. These resources will be utilized as references in the modeling and texturing process.



Figure 12 Granary (Kruithof, 2016)



Figure 13 Skeleton Granary (Kruithof, 2016)



Figure 14 Granary floor panels (Kruithof, 2016)

10.1.2. Model and unwrap

This step will allow the user to create the model by utilizing the references found in the previous step. The model in figure 18 was created by using the direct modeling method, which allowed the user to manually create the model. Firstly, the skeleton was modeled according to figure 13. Then in figure 16 more details like planks and other wall decorations have been added. After this process the mesh went through a check to see if there were any problems that could give issues, N-gons for example (Alexandrov & Burrows, 2019). This was done using the clean-up tool from Maya. After this the model was unwrapped by using Maya's UV toolkit as can be seen in figure 17.

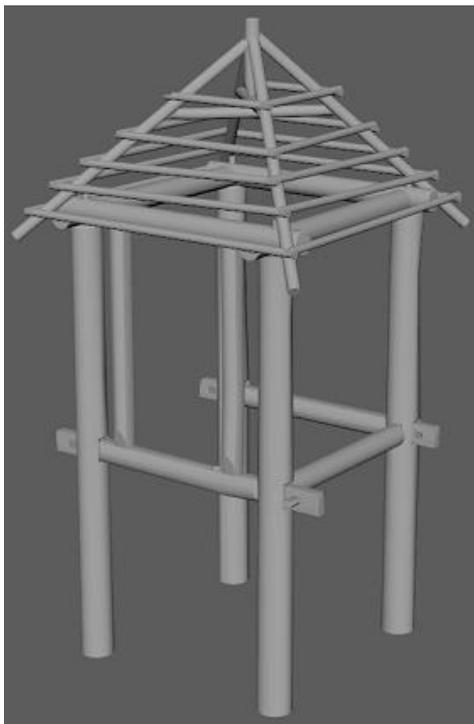


Figure 15 3D skeleton

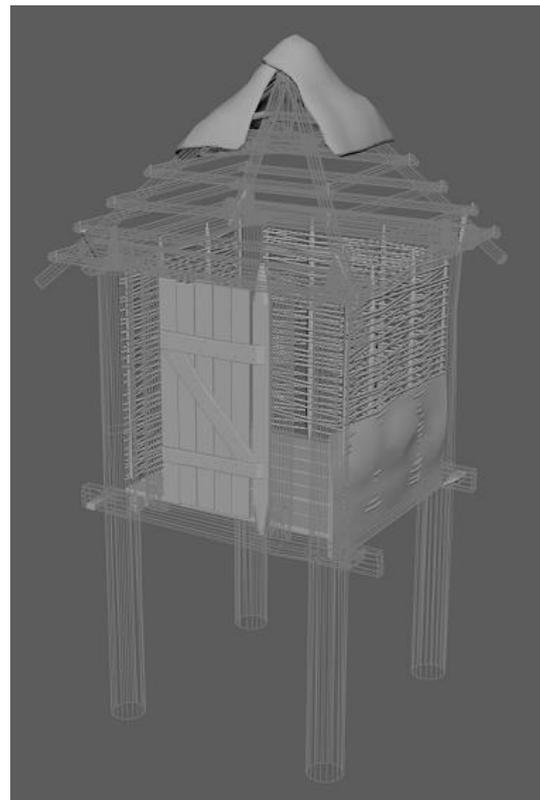


Figure 16 3D Detailing

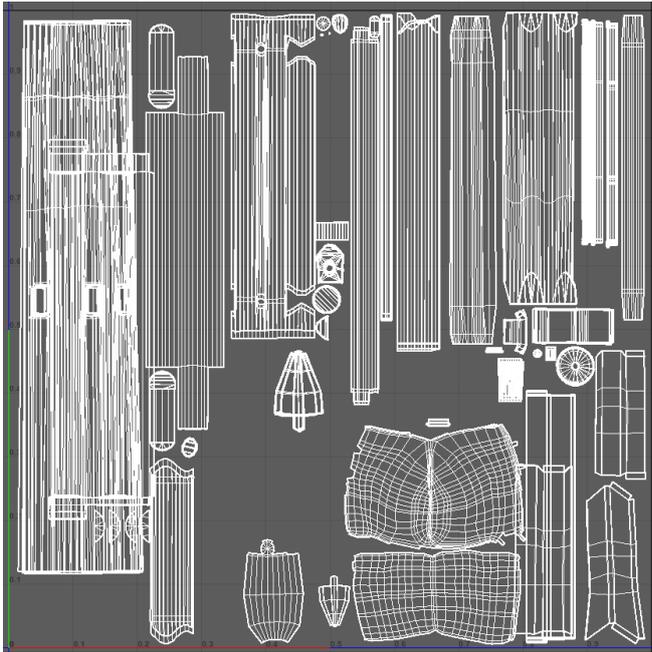


Figure 17 Unwrap



Figure 18 Combined 3D model

10.1.3. Texture

This step requires the user to create the texture in a texturing tool, for this purpose Substance Painter was used. Mostly wooden textures were used and an opacity layer was created for the thatched roof.



Figure 19 Texture map



Figure 20 Textured 3D model

10.2. Proposed workflow

Combining the steps from both workflows requires some thought of the practical process beforehand. This process is as described as seen in figure 11, but the identical steps of the traditional workflow will not be repeated.

10.2.1. Reference

See section 10.1.1. and 'Getimmerd Verleden' (Waterbolk, 2009).

10.2.2. Filter and define

There are several parts of the model that can be defined. The pieces of a structure that can be used to build the structure. The base of these structures consists of findings made from postholes that have been found at archaeological excavations (Waterbolk, 2009). There are four main pillars, these pillars are connected to each other by logs placed horizontally between them. Two of these logs go completely through the main pillars and two are carved in partly, together creating a, from a top view, square or rectangle shape.

Planks lay on top of two of the horizontal connecting logs, a total of seven. On top of the four main pillars four horizontally placed logs are put in place, this is the base of the roof skeleton. There is a door as entrance, which is supported by two vertical beams. On the walls there are willow branches that are bound together by two vertical logs. The roof skeleton has four main roof logs that together form an 'X' shape from a top view, these are structured diagonal and with an upward angle. In the middle of the four roof logs that form an 'X' is a vertical log that holds them together. Six smaller logs are laying horizontally on top of the roof skeleton on each side of the roof, four sides in total.

10.2.2.1. Test



Figure 21 Filter and Define collage

10.2.2.2. Iteration based on testing

The process of filtering and defining can be altered so a document, or asset list, is written so that models that need to be created are specifically stated so a better understanding of the workload is possible, on top of the already existing filter and define collage as seen in figure 21.

10.2.3. Model, unwrap and texture

See section 10.1.2 and 10.1.3.

10.2.4. Parametrization

This process requires knowledge of what needs to be parametrized and what outcomes are expected. Meaning there must be a desire for a series of outcomes, that will be enabled by parameters build inside Houdini. It requires an argument on what needs to be parametrized, what parameters can be randomized and to what end, and what is not parametrized and/or randomized. This needs to be a well-founded argument so there will be no feature creeping, “*a tendency to constantly add features which inevitably leads to complex products that are confusing and hard to use*” (Harvey, 2016). The parametrization process allows the user to get a clear view of what needs

to be done inside Houdini and how this should take place. Inside Houdini the need of parameters will enable the creation of a ruleset.

10.2.4.1. Test

Firstly, different house plans need to be used as input data that can be converted. Secondly, the height of these main pillars needs to have a parametrized range, so different height granaries can be built. Thirdly, the diameter of the main pillars needs to be adjustable within a range so postholes with different diameters can be processed. The main pillars need to be connected with the horizontal logs, all horizontal logs on the X axis will go completely through the main pillar, all horizontal logs on the Z axis will only cut half way inside the main pillars, these medium logs will have a parametrized diameter. The logs on the X axis will have a pin connection that makes sure the log cannot disconnect from the main pillar, this pins' position will be parametrized within a range. The length and amount of these medium logs on the X and Z axis will be connected to the position and number of main pillars.

The number of horizontal planks will be parametrized and the width and thickness on both sides of all individual planks will be randomized with a range in thickness and in width. The length of the planks will be connected to the distance in between the main pillars that are connected on the X axis. On top of the main pillars horizontal logs are placed for the roof structure, these will be parameterized in diameter within a range, as well as the amount and length of these logs are depended to the position and amount of main pillars and will be parametrized.

10.2.4.2. Iteration based on testing

This step takes a lot of documenting, and thus writing makes it hard to comprehend the total structure. Recommended is to merge the parametrization step with the ruleset step, so a clear connection between the ruleset and the parametrization step is possible.

10.2.5. Ruleset

This ruleset is the base of which the nodes in Houdini will be created and will enable the user to manage and influence the model with parameters without breaking it. This ruleset also needs to be maintainable, so that another user can also change rules and parameters if needed. Before creating a ruleset in Houdini, one must explain the ruleset and interactions. To do this an influence diagram will be created to visualize the rules that are needed by using the parametrization step, so all connections and influences can directly be viewed and understood by any user.

10.2.5.1. Test

In figure 19 an influence diagram can be seen that shows the functionality that needs to be created. This diagram will be built inside Houdini and will enable users to plan functionality and make the tasks manageable. This diagram makes the steps clear and plannable.

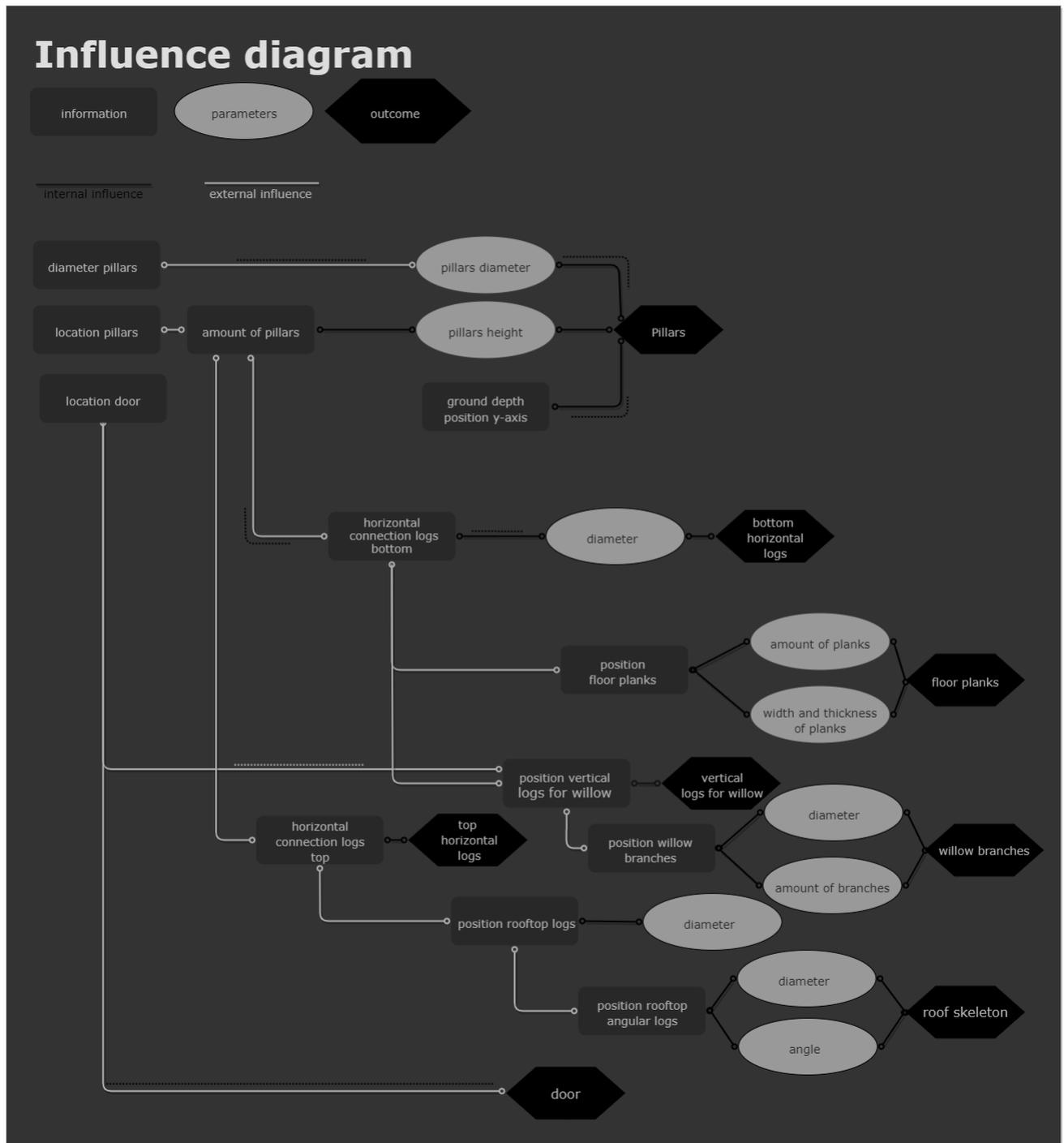


Figure 22 Influence Diagram

Following the diagram, the functionality will be made within Houdini. However, there is a multitude of functions that can be executed in Houdini to get the same result. For example, to create a group inside Houdini the user can create four different nodes; Group, Group Create, Group Range and Group Lasso, and in theory they could all give the same result.

Therefore, an influence diagram is important to get a systematic process without going too much in-depth in Houdini, like nodes used and code that is needed. This step requires the user to have knowledge of Houdini. The rule of which everything will be based on is the location of the pillars which will be extracted from excavation maps that can be found in *Getimmerd Verleden* (Waterbolk, 2009). This data needs to be scanned by a printer so it can be digitally accessible, figure 23. Once this has been done a filter needs to be used in an image-editing tool, for example Photoshop, so the information that is needed can be filtered out, as seen in figure 24.

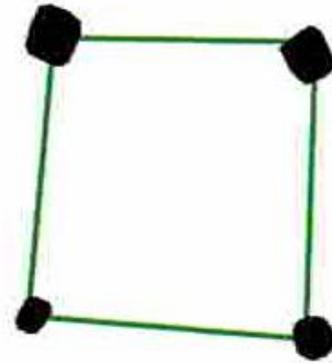


Figure 23 'Getimmerd Verleden' Housing plan (Waterbolk, 2009)

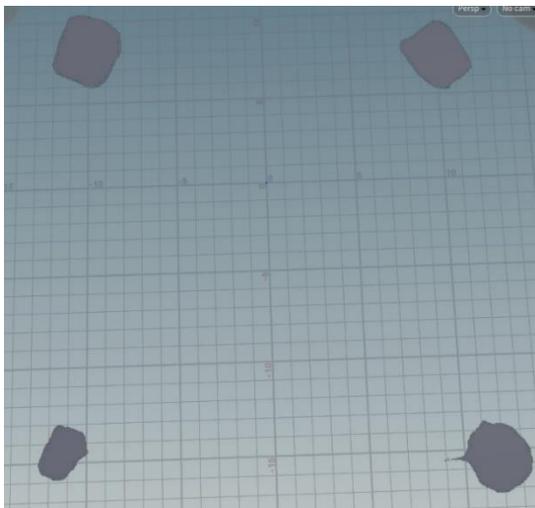


Figure 24 Filtered data

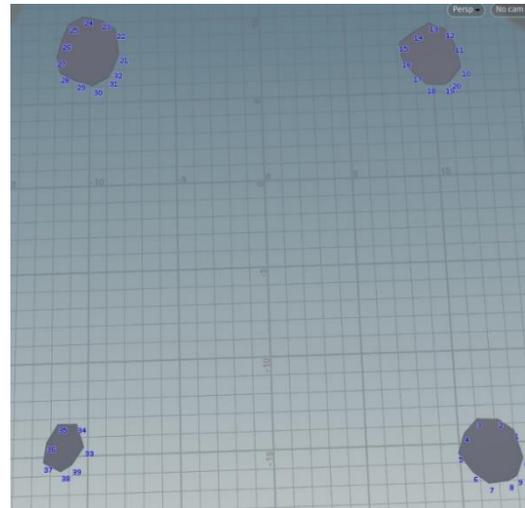


Figure 25 Point data

All post-hole sizes are normalized so they roughly share the same average diameter, this is done after consultation with archaeologists. It was argued that the postholes are not complete accurate because of soil changes, crooked poles, and other causes. To ensure consistent results an average post-hole is picked and used as a base for the normalization process.

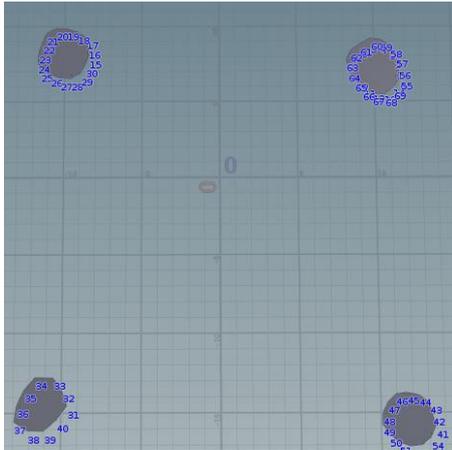


Figure 26 Normalization

After normalization, the functionality can be built on top of this foundation. Centre points will be created in the middle of each post-hole, as seen in figure 27.

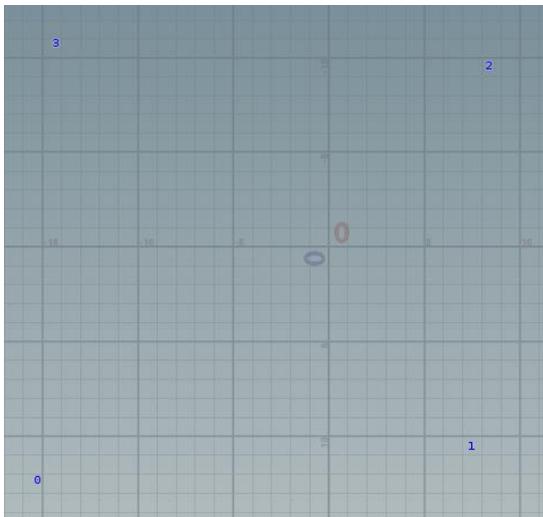


Figure 27 Center pole points

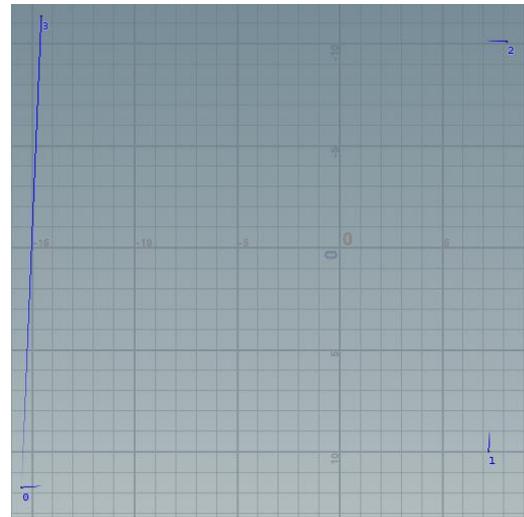


Figure 28 Input direction pole points

These points are then connected by a line and direction information is added to each point. This direction is then pointed towards each consecutive point from the current point, as can be seen in figure 28. On each point a horizontal log is placed that includes the same orientation and rotation values as the point it is placed on, as can be seen in figure 29. These points are then transformed and copied upwards to create the top horizontal logs.

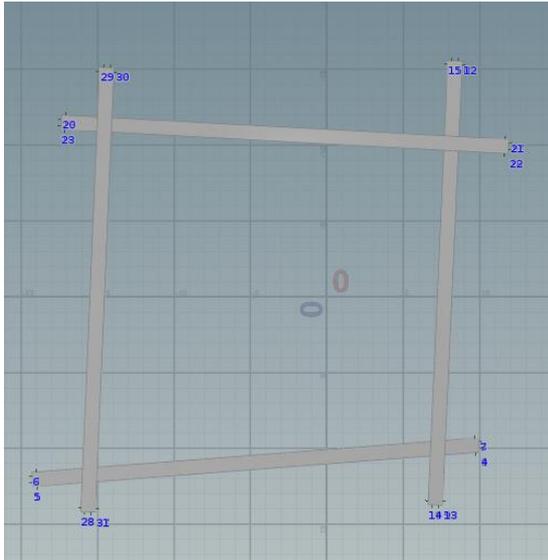


Figure 29 Horizontal logs

To create the vertical logs that hold the willow branches, more points must be created. The corner points are removed, as seen in figure 31, to ensure the models only get copied to the correct points.

The vertical logs are then copied to the points.

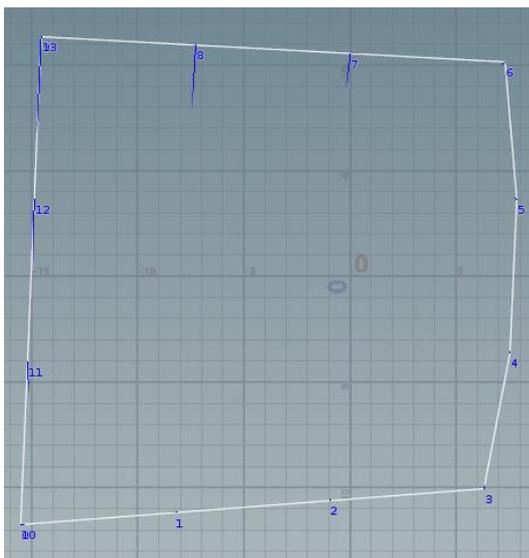


Figure 30 Vertical logs points

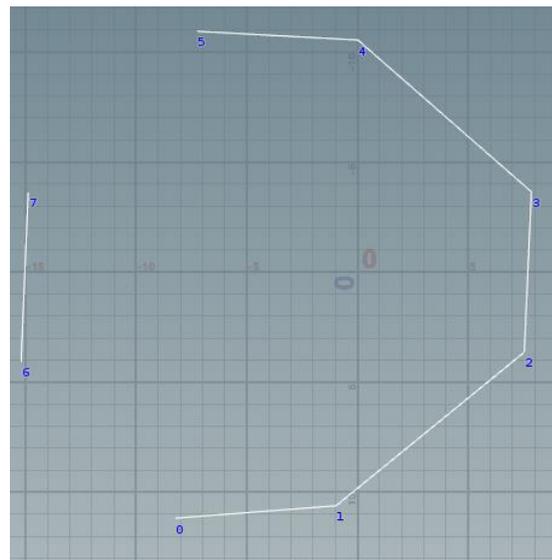


Figure 31 Corner points removed

To create the roof, the same points are used as in figure 27, these points are transformed upwards. In the center of these points a point is created and transformed upwards, as can be seen in figure 32. In between the centre point and the four other points lines are created, the orientation and rotation of these lines is then used as values for the roof logs to be placed on.

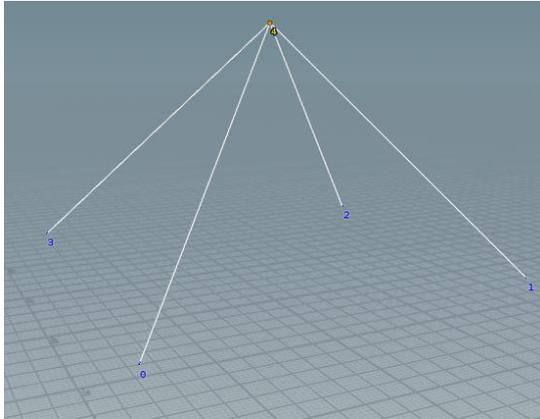


Figure 32 Centre point transformed up

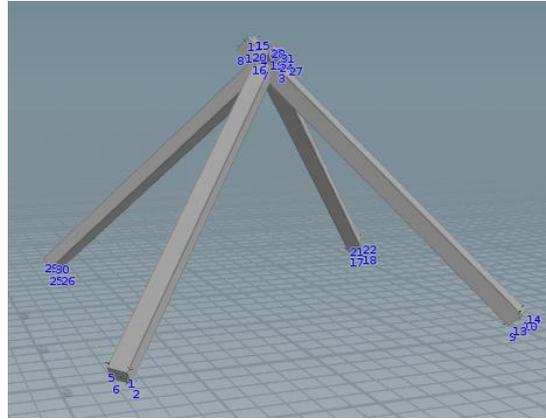


Figure 33 Roof logs

Points are scattered over lines of figure 34. These points are then given directional values that point toward each consecutive point, paired per four, so the base of the smaller roof logs can be created, as demonstrated in figure 35.

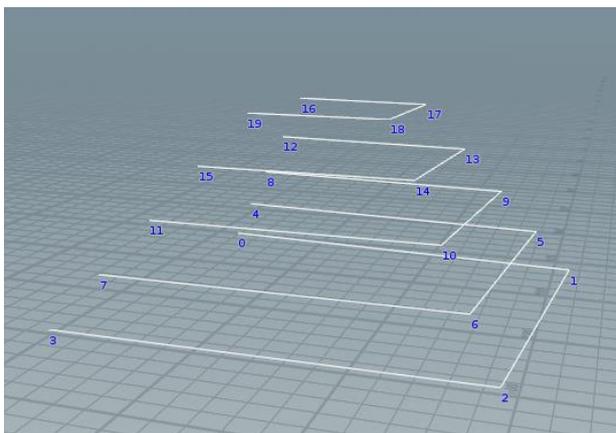


Figure 34 Roof points

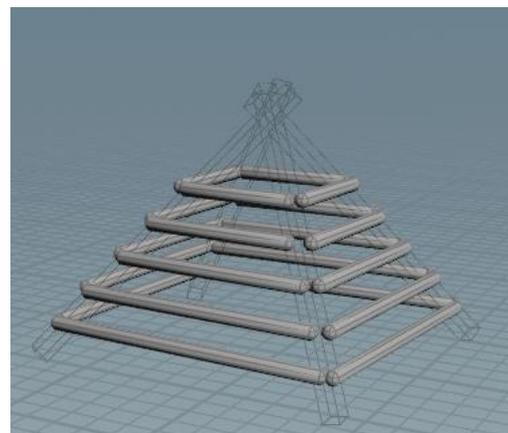


Figure 35 Roof logs

The vertical logs that hold the willow branches are placed on points that are scattered over the lines as seen in figure 36.

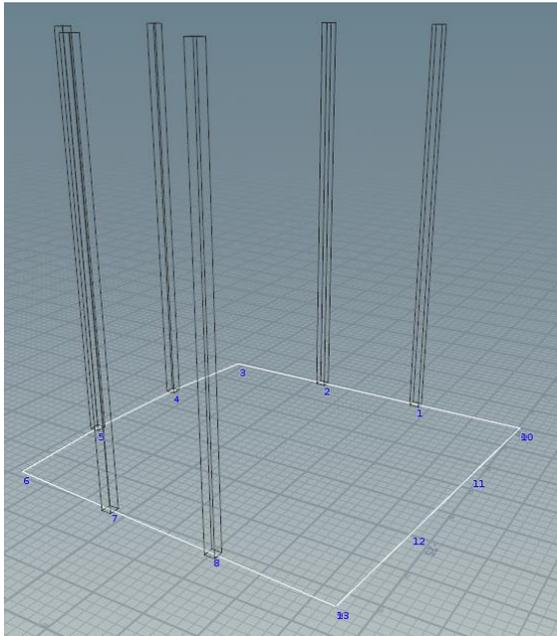


Figure 36 Vertical logs for willow

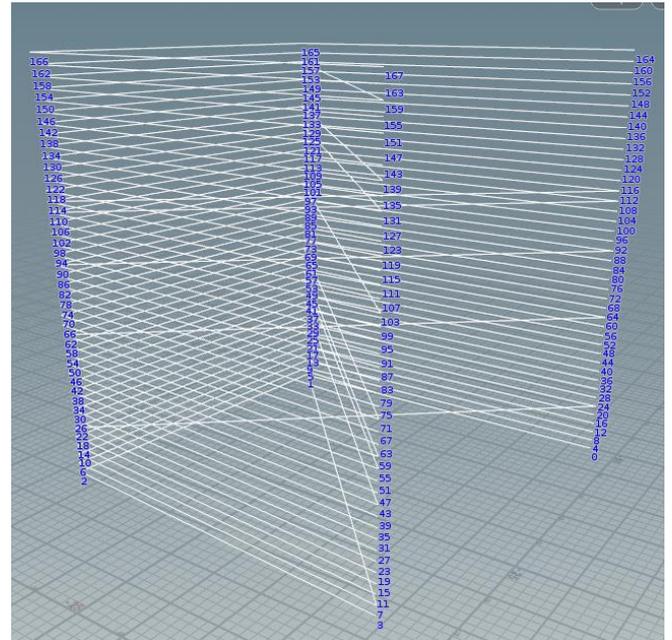


Figure 37 Willow points

The points in figure 36 are used to create the points for the willow by deleting all points except the corner points. These corner points are then duplicated and transformed upwards, as demonstrated in figure 34. The willow models are then copied on top of these points, including direction of the points. This process is duplicated so two different versions of the willow can be placed.

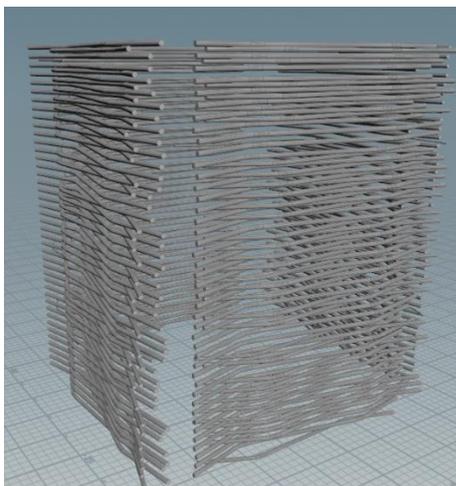


Figure 38 Willow

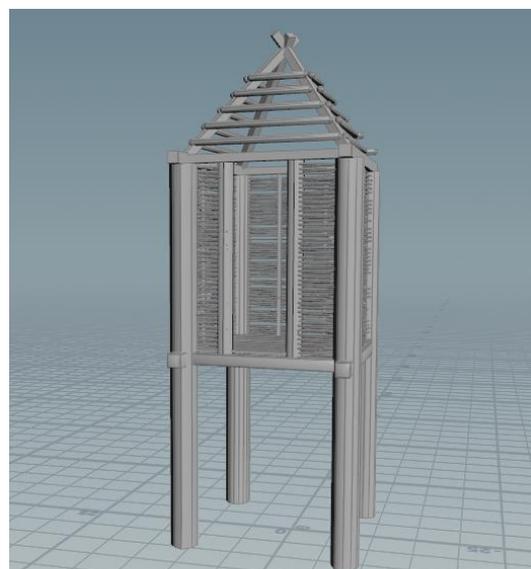


Figure 39 Final result

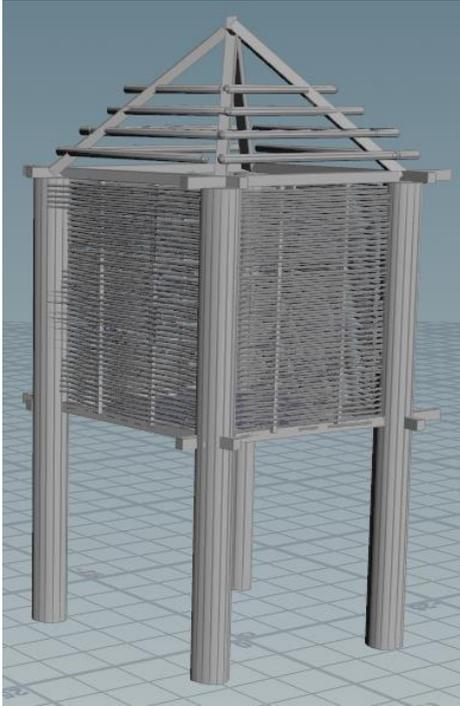


Figure 40 Final result, different data input

The final result is a functional system, or rule-system, that can utilize data input to form a model.

A parameter interface is added so the user can input data for the model that is required, this is done by referencing nodes inside the network editor and creating a menu from these nodes, as seen in figure 41.

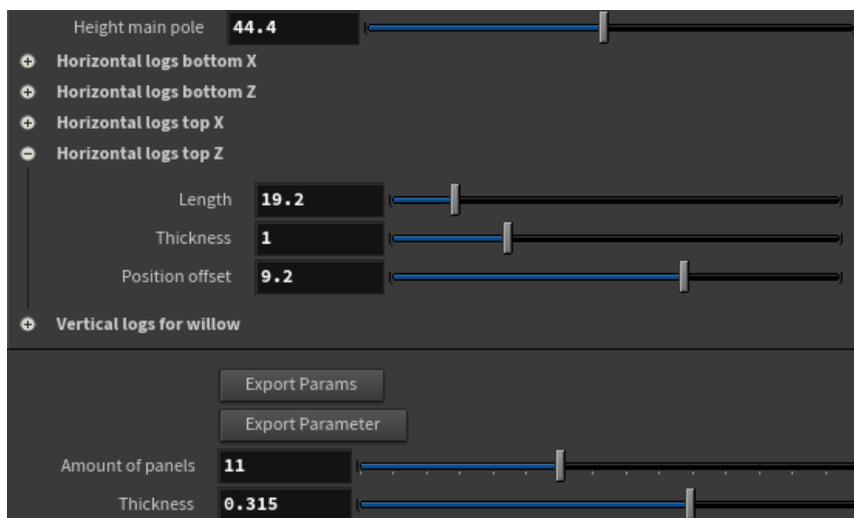


Figure 41 Parameter UI

These parameters can also be exported to a text document so user input can be exported and shown in a text document. To enable this a small code in Python was written that lets the user choose what parameters they want documented, as demonstrated figure 42. This ensures TijdLab has scientific data that is documented after changes are made to the parameters that are built.

```
f export_params(kwargs):
    print("parameter exported")

    ## get parent node##
    parent = kwargs['node']

    ## get params##
    Height_Main_Pole = str(parent.parm('Height_Main_Pole').eval()) + '      Height Main pole' + '\n'
    Length = str(parent.parm('Length').eval()) + '      Length horizontal log bottom X-axis' + '\n'
    Thickness = str(parent.parm('Thickness').eval()) + '      Thickness horizontal log bottom X-axis' + '\n'
    Length3 = str(parent.parm('Length3').eval()) + '      Length horizontal log bottom Z-axis' + '\n'
    Thickness4 = str(parent.parm('Thickness4').eval()) + '      Thickness horizontal log bottom Z-axis' + '\n'

    ##write to text file##
    lines = [Height_Main_Pole,
            Length,
            Thickness,
            Length3,
            Thickness4]

    path = 'C:/Users/info/Desktop/writtenpy/settings.txt'
    f = open(path, 'w')
    f.writelines(lines)
```

Figure 42 Export code snippet

The model is unwrapped using different techniques, this could later be textured. All UV's are procedural which means they scale when parameters are altered.

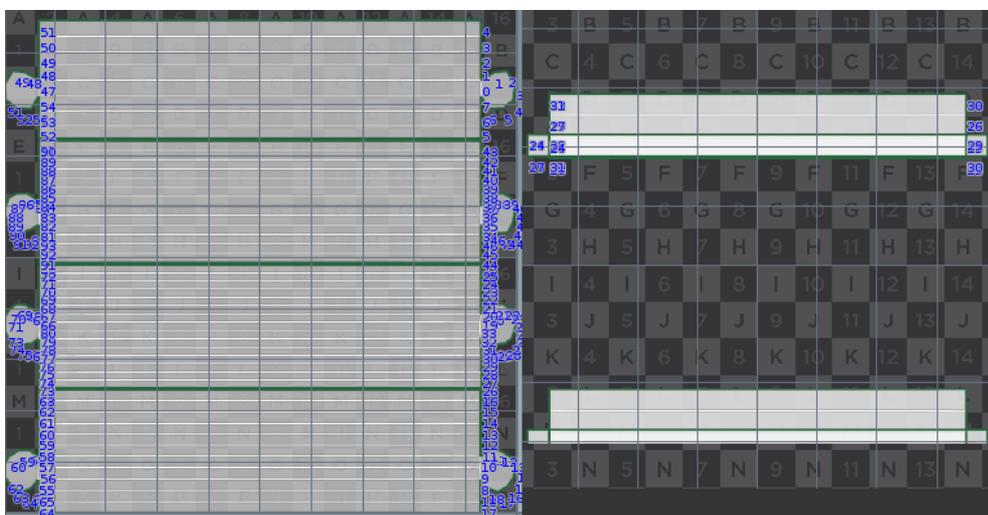


Figure 43 Unwrapping snippet

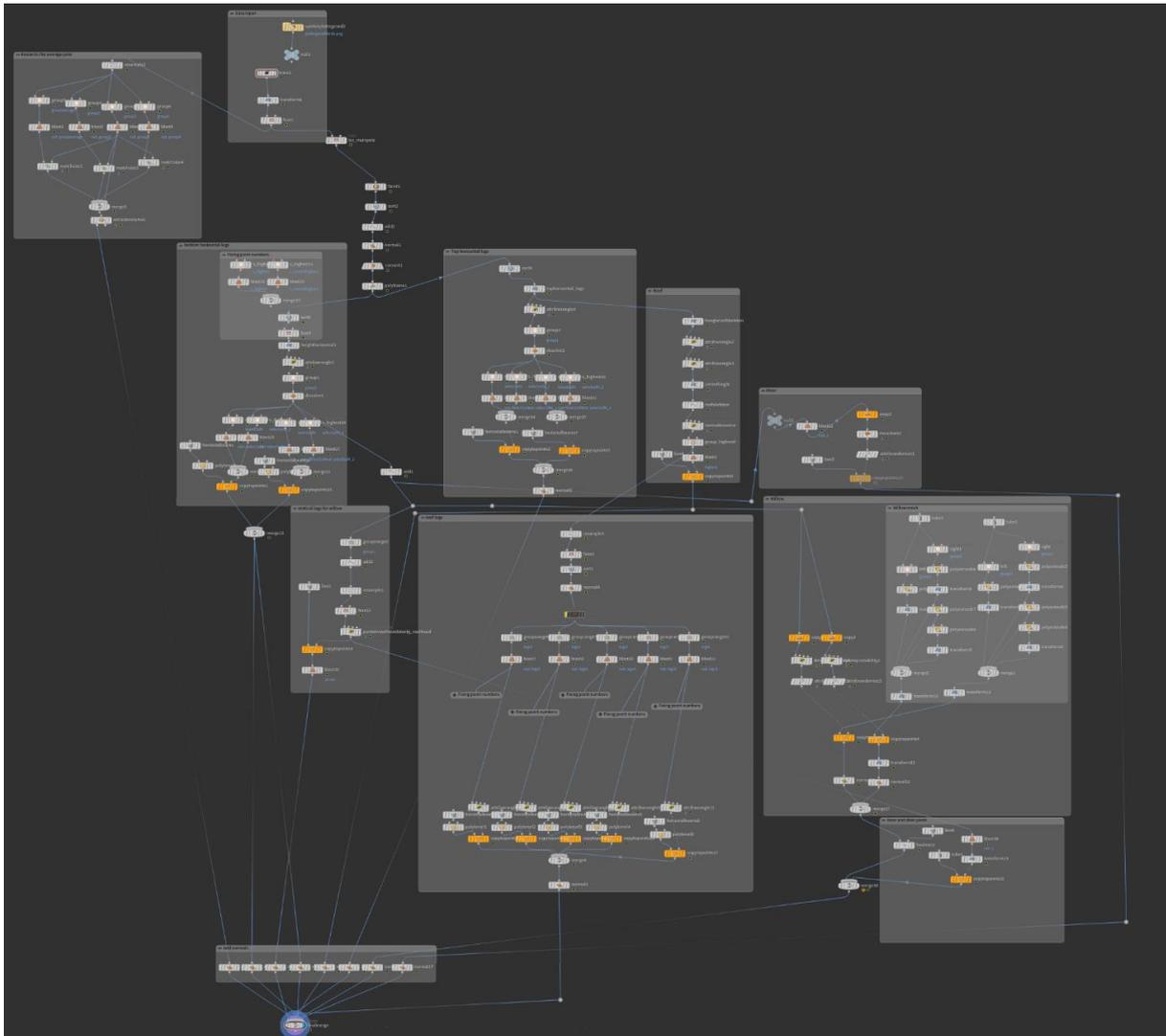


Figure 44 Network view

The network viewport gives a final impression how the ruleset is setup and how models are connected to this functional system.

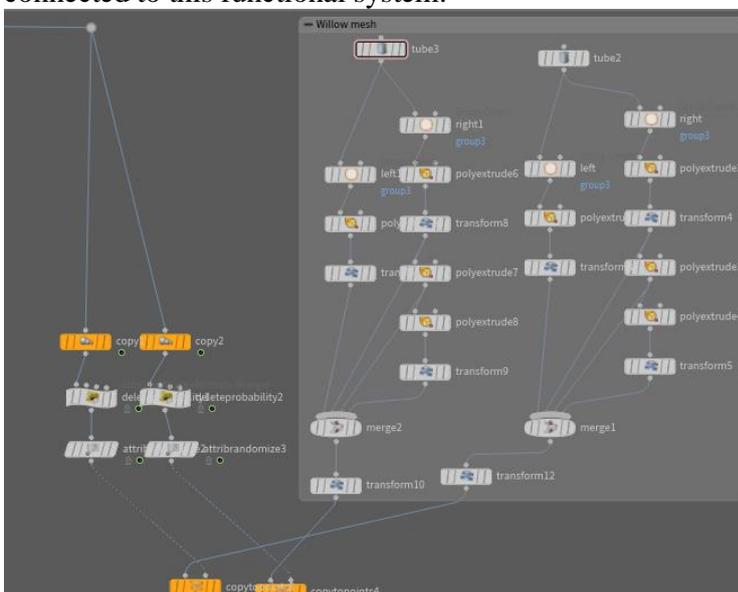


Figure 45 Snippet of rule-system

10.2.5.2. Iteration based on testing

This step is setup properly.

10.2.6. Importing

Models that were created in the modeling, unwrapping, and texturing step (paragraph 10.1.2 and 10.1.3) will be imported in Houdini, and placed inside the functional system created in the ruleset (paragraph 10.2.5) that is created in Houdini.

10.2.6.1. Test

The models created in Maya were of good quality but not based on data that could be validated and extracted, so this was found not scientifically relevant enough.

10.2.6.2. Iteration based on testing

This step has changed to “model and unwrap” and is no longer done in Maya but instead in Houdini. It is moved behind the rule system step, this means after the functional system is in place the models can be created and unwrapped, as can be seen in Figure 46 Proposed workflow version 2

10.2.7. Maintenance

This step allows another user to get a quick and clear understanding of how the system is setup and creates a clear view also for archaeologists. It makes changing or adding rules and/or parameters easier, especially in larger projects and where multiple disciplines must work together.

10.2.7.1. Test

After creating the influence diagram (Figure 22 Influence Diagram), it was found out this was a proper way to create a quick and clear understanding of how the system works, this will allow for easy and quick maintenance to projects.

10.2.7.2. Iteration based on testing

This step is moved before the ruleset setup and include the influence diagram, so it can be created before the functionality and updated after most work has been done so it can be utilized as maintenance ‘book’, as can be seen in Figure 46 Proposed workflow version 2

10.3. Proposed workflow revised

The proposed workflow has been iterated based on the outcomes of the tests. The most notable change is that Maya is no longer part of the workflow, so the import step has been discarded. The maintenance step is combined with the parametrization step and placed before the rule system step, so the rule system can be based on the influence diagram where all parameters and connections can be displayed and later be used as a maintenance ‘book’ to get a quick and clear view of the functional system.

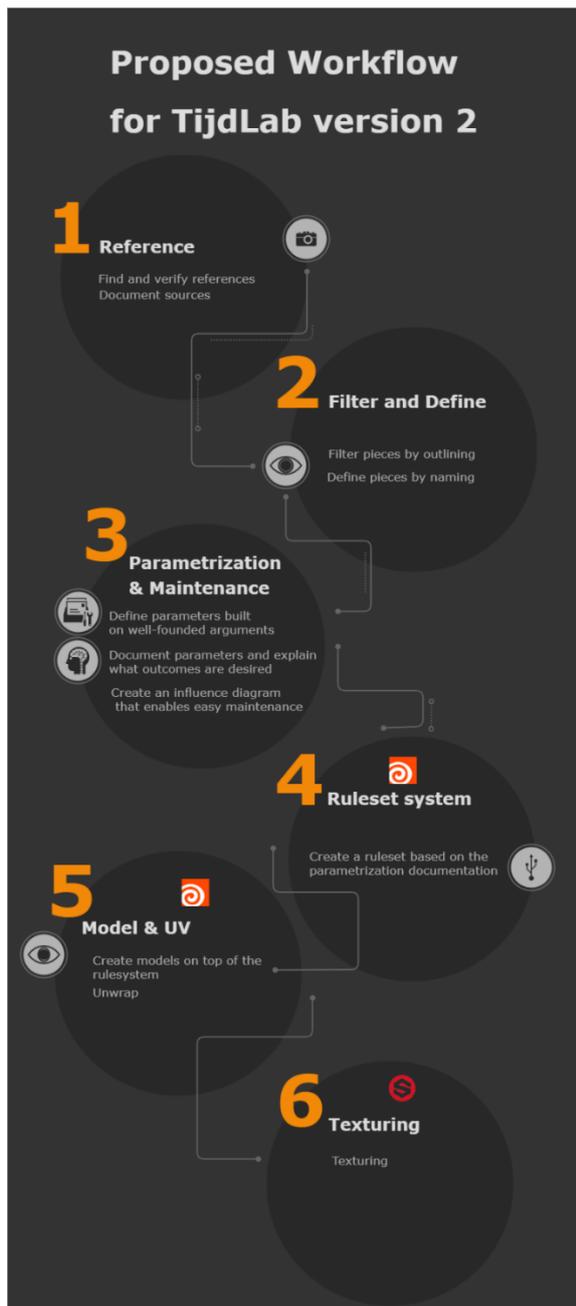


Figure 46 Proposed workflow version 2

10.4. Testing method

The A/B testing method will be used to test the differences between the traditional workflow and the proposed workflow. The criteria used for this testing method are production and labor costs. These two metrics will be compared for both workflows and thus the testing results will be used as basis for a conclusion on the workflows.

10.4.1. Testing conclusions

Executing the traditional workflow was timed at a duration of twenty hours, every consecutive asset took a little less time. Executing the proposed workflow for Houdini took thirty-eight hours, every consecutive asset took considerably less time. The duration of texturing is not evaluated in the results because it is done in a separate tool and is equivalent for both workflows. The full tables can be found in the appendix.

Proposed workflow steps	Hours
Referencing	1
Filter and define	1
Parametrization & Maintenance	4
Rule system	22
Model and UV	10
<i>Texturing</i>	-
Total	38

Table 9 Proposed workflow hours

Traditional workflow steps	Hours
Referencing	3
Model and UV	17
<i>Texturing</i>	-
Total	20

Table 10 Traditional workflow hours

Different data inputs could be used inside Houdini to create different outputs, these do not work completely automated but little work is needed to make it function as supposed once a proper functional system is setup. In Houdini the workflow is replicable, data can be extracted and used in documentation and the workflow is replicable. In Maya the process is harder to replicate, models can be copy-pasted and edited manually but it is not created from data input and requires more time to adjust. The new workflow is more efficient than the traditional workflow when more than eight assets are created as can be seen in figure 47, where the total hours can be seen. Figure 48 shows a clear difference between the two workflows, each subsequent asset after the first asset takes considerably less time to create in the proposed workflow than the traditional workflow.

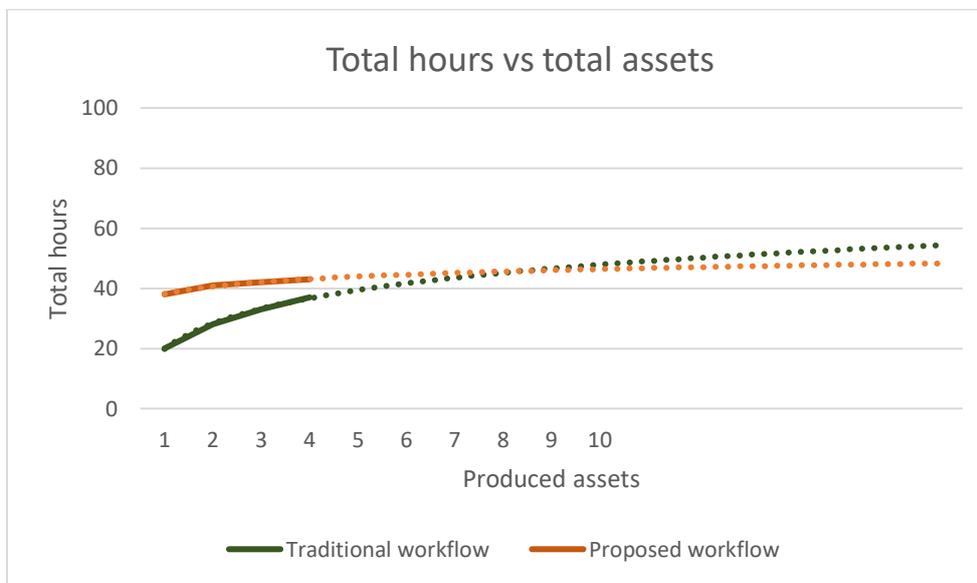


Figure 47 Total hours vs total assets

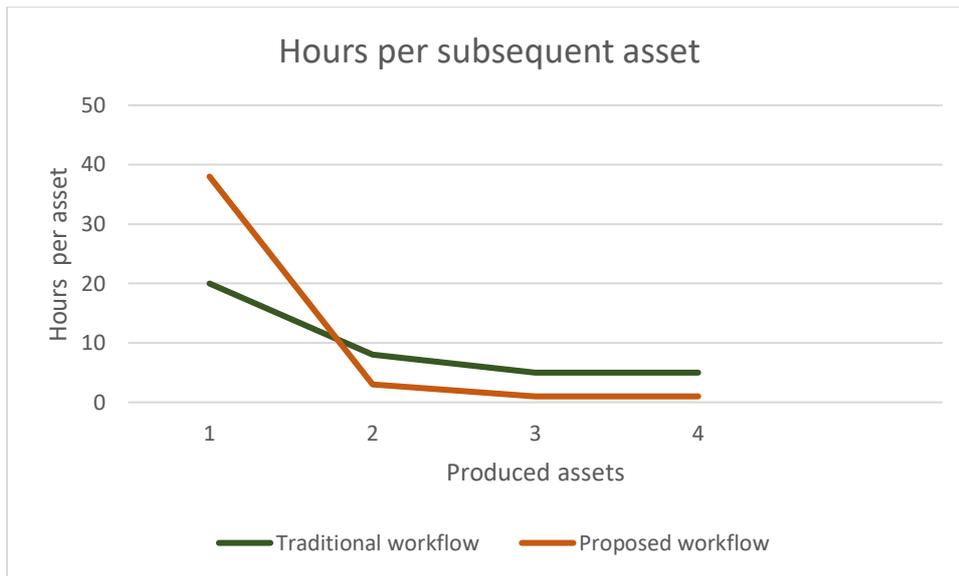


Figure 48 Hours per subsequent asset

It could be argued however that Houdini has a steep learning curve and therefore the data that is generated in figure 47 and figure 48 can be interpreted in a way that it is slightly negative because the test was executed by a non-experienced Houdini user. Thus, it can be assumed that an experienced Houdini user needs less hours to create the first asset. Based on this information it can be concluded that the graph in figure 49 gives a better impression of the predicted workload, where the initial investment is smaller for the proposed workflow.

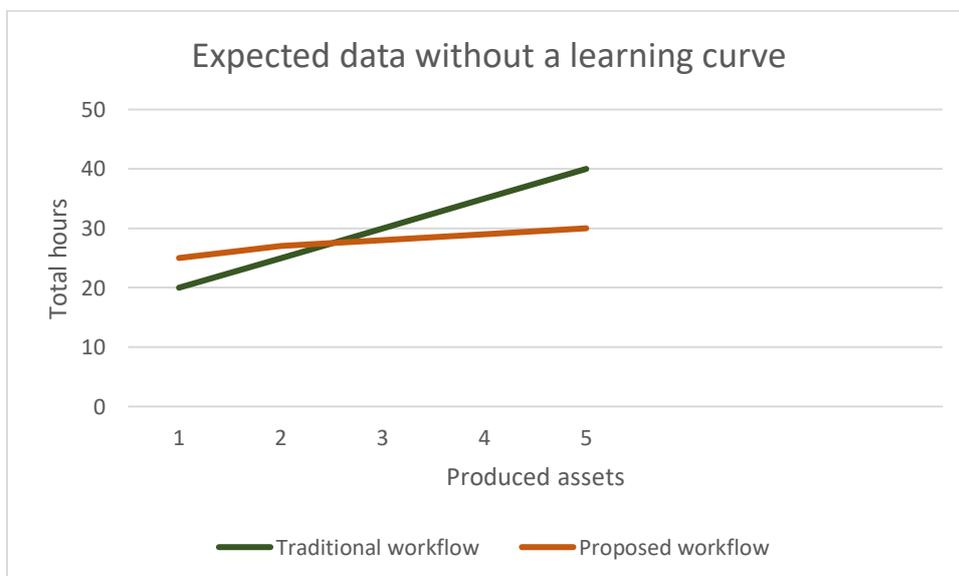


Figure 49 Expected data

11. Conclusion & recommendations

This work was aiming to create a workflow to model scientifically accurate longhouses in 3D based on house plans. The expected result was a workflow that would be replicable and more efficient than the current workflow, direct modeling, and that could be used in the company to enable this. The methods photogrammetry, direct modeling, and parametric modeling corresponding to their tools were tested with the weighted scoring model and seven criteria were used to analyze and quantify the test results to find out which method would work best. The results of testing the methods display a positive score for Houdini and Maya and a negative score for Reality Capture. In addition to this Reality Capture is also not usable for longhouses because there are no physical longhouses to photograph, therefore this method was not tested further. Research has been done into ways of dealing with data uncertainty, but because of the scope of this question no conclusive way to deal with this has been found and therefore further research on this topic is required. Two workflows were used/developed and tested for the tools Maya and Houdini & Maya. The traditional workflow utilized Maya and the proposed workflow focused on combining Houdini and Maya. However, after testing the first version of the proposed workflow it turned out to be better not to use a combination of both tools but only use Houdini. This decision was made to prevent meta data noise from detracting from the archaeological relevance of the models. After using the criteria production and costs to A/B test the traditional workflow and the proposed workflow, it was found that the proposed workflow is more cost efficient after more than eight assets were created. The proposed workflow is more efficient because it uses a functional system wherein data input can semi-automatically generate models. In the traditional workflow the input is bound to human labor, inherited to the method of modeling. In addition, the proposed workflow gives a more replicable output and parametrized data can be extracted from the tool. The drawback to the proposed workflow is that it requires more short-term investment than the traditional workflow and that creates a bigger initial financial risk.

Though, in the long-term this means less financial risk because costs go down dramatically after the functional system is setup and less to no investment is required afterwards. Therefore, it is recommended that the proposed workflow is used because of its advantages in the long-term, where efficiency and scientific relevance is an important factor, and multiple non-unique assets are needed. The proposed workflow can also be adopted for other relevant archaeological projects, but more testing needs to be done to further proof and improve the workflow.

12. Reflection

The first month of my research I focused mainly on getting a better scope and goal for my research. Choosing a topic I was not familiar with allowed me to broaden my knowledge, in this particular instance I learned a lot regarding archaeology. Important archaeological topics in relation with my research were discussed with Rob van Haarlem and I incorporated this in my research. It made me aware of certain archaeological standards that are needed in this specialized field. Furthermore I learned to behave professionally, I went to local business meetings that were held and it helped me improve professionally because I had to ‘work’ and communicate with people that had their own business up and running, I did not experience this yet before my graduation. My graduation coach, Alejandro Moreno, helped me get a better understanding of researching and gave valuable feedback to my work, this helped me notably to become more specific and to the point in writing and researching. Quickly after six weeks though the Corona virus came and I had to work from home. It was harder to keep up with the same amount of work I would get done in a normal workday at the company, especially in the first month. Thus, I made a work schedule and tried to stick to that, this helped me improve my productivity. I learned to work with a new tool, Houdini, by realizing a workflow for longhouses. This tool was quite unusual to me because it bases the outcome of models on functions and data input and required me to think completely different from the standard 3D tools taught at CMGT that are mostly based on direct modeling. I think the practical result would have been more extensive if I took a more systematic approach to learning Houdini. Therefore, if I would start a new project and had to learn new software that is as complex as Houdini, I would probably do a full training course to get started before working on that project. Additionally, help from colleagues was burdensome when learning this software, of course we had a lot of online communication when working from home, but nevertheless the learning curve became much steeper because I had to find most things out myself. My expectation management was also a bit too high, the scope of sub-question three was too extensive as noted in the conclusion. This is a good learning point for me to be more critical about expectation management and adjust

it in a more agile way. Though I am confident in the outcome of this research and its usefulness that it will have within company.

13. Appendix

Analysis per criterion

13.1.1. Perceived ease of use

According to a comparison done by G2.com ("Compare Houdini vs Maya"), the ease of use for Maya is graded with a 6.7/10 and Houdini with a 5.6/10, where 10 is intuitive and 0 is non-intuitive. There are two reasons for this: 1. Maya is a direct model tool, almost everything you do an interact with is visualized, 2. Most used modeling tools in game development are direct model tools (Fram, 2017) which makes it inherent that if a person has already been in contact with similar direct model software, thus making the perceived ease of use higher. Houdini on the other hand is a node-based, most of the process is taking part inside the 'Network editor' ("Network editor"), this shows a hierarchical list of all nodes in the scene, where the user creates a node-systems, the process that takes place in expressions and functions, that defines the visual representation in the viewport. This makes the workflow of Houdini to unexperienced users unfamiliar, thus less ease of use. For experienced users this is different, Maya's UI has customization available, but some settings are hidden behind other menus, Houdini does this better, by having a clear search bar and node system, as well as a complete documentation. Reality Capture UI is similar to Microsoft Word and is easy to get familiar with. The software is simple, less complex than Maya or Houdini, this in combination with the familiarity of users that have used Microsoft Word, makes the perceived ease of use high.

13.1.2. Flexibility

Maya's workflow is inherently less flexible. Maya works in such a way that every change the user makes to a mesh is stored in the 'surface history'. These changes are mostly made through manual selections and edits inside the viewport. This history is also visualized in the node-editor. The history in Maya can become very complex and long which is in itself not a problem, but the node editor in Maya is complex to edit and read because there is not one input and one output for each

node, but a multitude of outputs and inputs, organizing this node-view is not do-able and will reset back to its original layout when you edit a node.

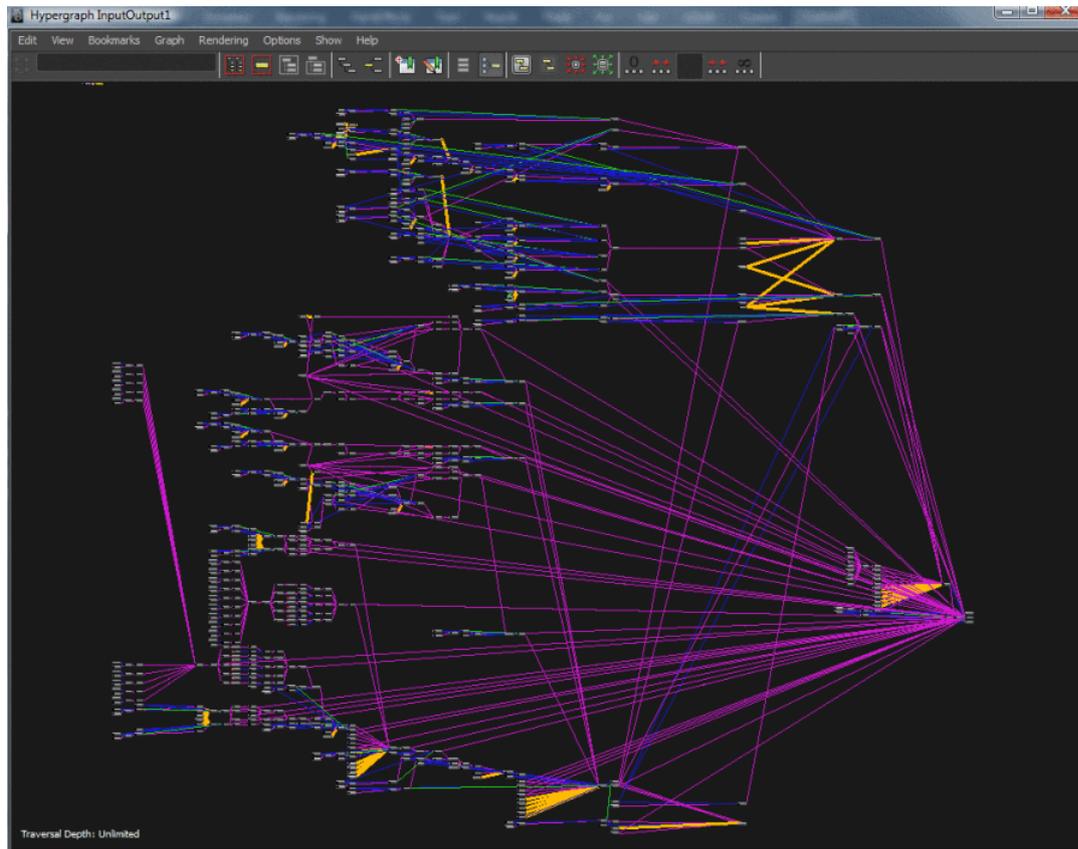


Figure 5 Maya node-editor

In Houdini the ‘Network editor’ is much cleaner and changes to objects are mostly made inside this ‘Network Editor’, most nodes have one input and one output and arranging these nodes is more user-friendly, the user can add notes and move nodes. Furthermore, in Maya complex logic is harder to ‘render’ because vertices only store a position, Houdini on the other hand, can store and exchange any data created by the user within these points (Estela, 2011). This makes Houdini more flexible. Reality Capture is a capture software, the user uploads a series of pictures, Reality Capture processes these pictures and creates a point cloud that is rendered as a mesh, this make it inherently less flexible than model software because very limited changes can be made to the

13.1.3. Iterative capability

The iterative capability of Houdini is basically the concept of the software. It has a node-based procedural workflow that make it easy for the user to create iterations of the work, as well as build-in and custom parameters that can be controlled by the user to generate different results. Maya, as mentioned above, works with a history that needs to be deleted every once in a while, to maintain stability of the program, this makes it impossible or very difficult to return to previous versions of the work, especially with complex objects. Maya does have some iterative capabilities, but nowhere near what Houdini has to offer, because it was not designed for it. Reality Capture iterative capability is very limited, as mentioned in point 2, when data has been processed by the software it created a point cloud and a mesh has been rendered, but after this process changes are very limited.

13.1.4. Quality output related to low-end devices

Both Maya and Houdini offer good quality output related to low-end devices. Both are similar in this case, Maya's optimization is mostly based on user interactions, for example removing unwanted geometry. Houdini optimization means going inside the 'Network editor' and changing parameters. Both offer the same optimization but with other methods. So, the optimization and quality output depend solely on the expertise of the artist. The quality output from Reality Capture is high, but optimization for low-end devices is limited to reducing polygons with an algorithm. This means an external program is necessary to optimize and re-topologize a model.

13.1.5. Reproducibility and replicability

In Maya the reproducibility and replicability of a work using the same workflow is more difficult than in Houdini. Maya's workflow makes the creation of objects personal, because by interacting in the viewport with the model the user performs certain tasks on the model that cannot be discovered by another user when the history of the object is deleted. In Houdini the 'Network editor' is basically a list of logic operations that the user creates to shape an object. This makes it inherently better for reproducibility because the steps in the workflow are clearly visible and can be exactly reproduced by another user. Reproducibility in Reality Capture is difficult, because there

is no optimization for low-end devices, this means it will ultimately rely on the manual work that will be done in an external program, which is difficult to reproduce/replicate.

13.1.6. Sustainability workflow/software

Houdini official released in 1996 ("Houdini (software)", 2020). Maya officially released 1998 ("Autodesk Maya", 2020). Maya's license process is made so if you want to keep using an old version, or update to a newer version, that with both options the user must keep paying periodically for using Maya, 2.033 euro per year. Houdini has 2 different kind of licenses, perpetual and periodic. 1.838 euro per year for a periodic license, and 2.760 euro for a perpetual license. The perpetual license allows the user to keep using the product with updates for one year, after this period the user can still use it, but does not get new updates unless paying for an upgrade plan which costs 1.495 euro. The perpetual license means the software is more sustainable for a user, the user can permanently use the software and pay extra if there is an important update, this means the workflow is sustainable with Houdini. Autodesk Maya could, for example, just increase the license prices whenever they want, which is a risk the company takes with periodic licenses. Reality Capture heavily relies on an external software to be able to output for low-end devices, this means the workflow risk is high because it relies on external software.

13.1.7. Cost per project

Cost per project can be answered by looking at the criteria above. The most important influence in costs is the project scope. The question that needs to be answered to know the scope is what assets are needed, and how many of these assets are needed. From here a rough estimation can be made, and thus arguments can be made to validate the choice of software. The second influence is labor costs. This is defined by the scope of the project and the software being used. The third influence is the costs of the software and hardware. Computer hardware requirements will be left out because this cost will be consistent across all compared software. This costs prediction will be based on one longhouse.

13.1.7.1. Reality Capture

Labor

Capturing data and processing data takes about one day, optimizing in an external program takes one of work, and baking the details is one day of work. This means for an eight-hour working day, twenty-four hours are required.

Software

Reality Capture costs 444.- euro per year.

Reality Capture workflow conclusion

The company assumes a sale of 4 longhouses per year, but when scanning two longhouses there should be enough assets scanned to create another longhouse without capturing more data, by manual labor. Creating a small library of scanned assets will take more time than only optimizing the assets. This means there will be an increase in manual labor and capturing cost will decrease when going for a library approach.

13.1.7.2. Maya

Labor

Finding and/or capturing reference takes one hour. Modeling a high-poly model from the reference takes three days, modeling and unwrapping low-poly takes one day, detail baking takes four hours, this adds up to twenty-nine hours.

Maya workflow conclusion

A lot of manual labor is required and licensing costs are high. Models made in Maya could be re-used, but this is not an automated process and manual work is required.

Software

A license for Maya costs 2.033.- euro per year

13.1.7.3. Houdini

Labor

Finding and/or capturing references takes one hour. Creating a functional system and modelling in Houdini takes six days, unwrapping one day, and detailing and baking four hours. This adds up to sixty-two hours.

Software

A perpetual license for Houdini costs 1.995.- euro.

Houdini workflow conclusion

Houdini has the highest costs in comparison with the other software, this is because the amount of work to create a functional system takes longer, but this system can later be used easily to create a multitude of assets by utilizing the same system, thus reducing workload in the long-term.

13.2. Comparison table

Traditional Workflow assets	Hours
1	20
2	7
3	5

Table 9 Traditional workflow hours

Proposed Workflow assets	Hours
1	38
2	3
3	1

Table 10 Proposed workflow hours

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