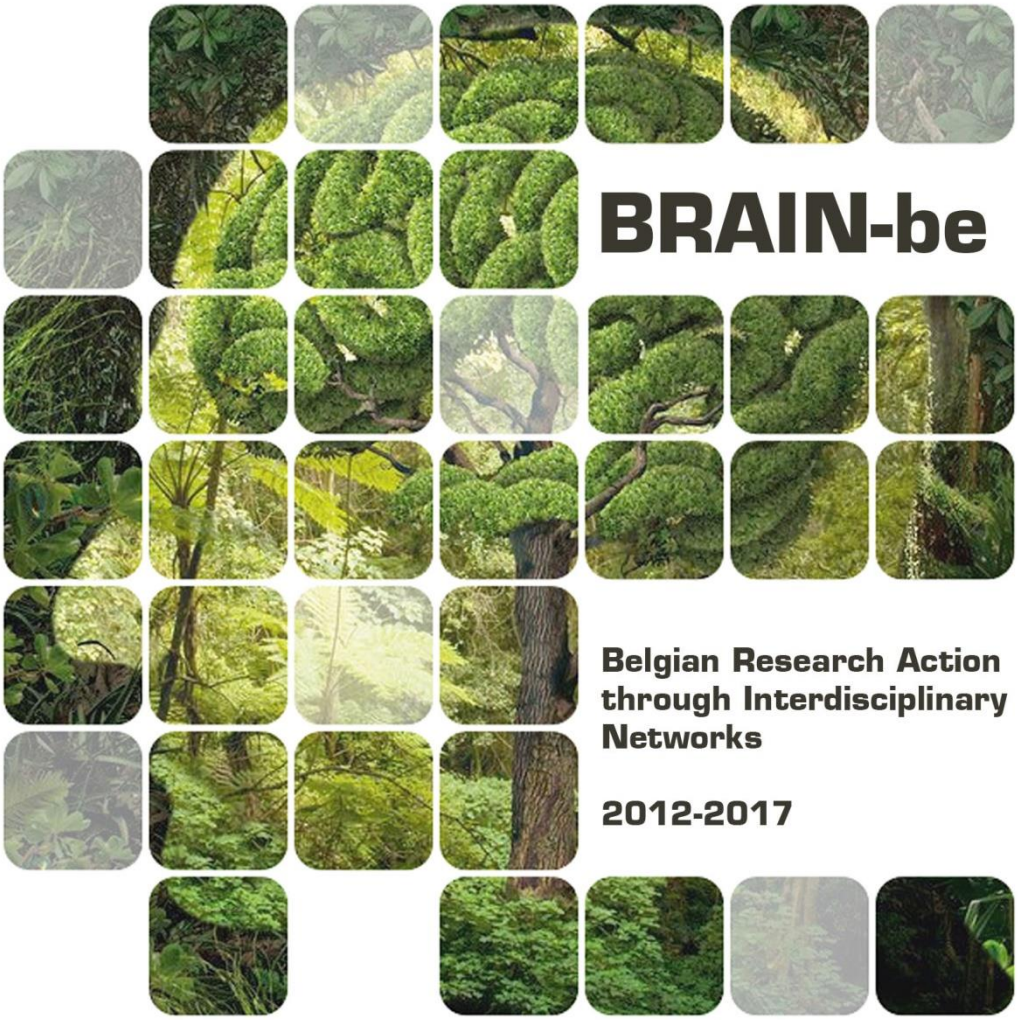

NEANDERTHAL-3D

Management and valorisation of the digitised Belgian human remains collection

AUTHORS:

Tara Chapman (Royal Belgian Institute of Natural Sciences)
Serge Van Sint Jan (Université Libre de Bruxelles)
Laurence Cammaert (Association pour la Diffusion de l'Information Archéologique)
Patrick Semal (Royal Belgian Institute of Natural Sciences)
Taha Jerbi (Vrije Universiteit Brussel)
Bart Jansen (Vrije Universiteit Brussel)
Caroline Polet (Royal Belgian Institute of Natural Sciences, Brussels)

Axis 3: Cultural, historical and scientific heritage

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NETWORK PROJECT

NEANDERTAL-3D

Management and valorisation of the digitised Belgian human remains collection

Contract - BR/175/A3/NEANDERTHAL-3D

FINAL REPORT

PROMOTORS:

Professor Serge Van Sint Jan - COORDINATOR (Université Libre de Bruxelles - ULB)
Laurence Cammaert (Association pour la Diffusion de l'Information Archéologique)
Bart Jansen (Vrije Universiteit Brussel - VUB)
Caroline Polet (Royal Belgian Institute of Natural Sciences, Brussels - RBINS)
Antoine Balzeau (Musée de l'Homme)

AUTHORS:

Tara Chapman (Royal Belgian Institute of Natural Sciences)
Serge Van Sint Jan (Université Libre de Bruxelles)
Laurence Cammaert (Association pour la Diffusion de l'Information Archéologique)
Caroline Polet (Royal Belgian Institute of Natural Sciences, Brussels)
Taha Jerbi (Vrije Universiteit Brussel)
Bart Jansen (Vrije Universiteit Brussel)
Patrick Semal (Royal Belgian Institute of Natural Sciences)

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WTCIII
Simon Bolivarlaan 30 Boulevard Simon Bolivar
B-1000 Brussels
Belgium
Tel: +32 (0)2 238 34 11
http://www.belspo.be
http://www.belspo.be/brain-be

Contact person: Georges JAMART
Tel: +32 (0)2 238 36 90

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ABSTRACT

Context

The Spy Neandertals have been extensively studied by both national and international researchers since they were found in 1886.

Objectives

The aim of the Neandertal_3D BRAIN project was to utilise the existing digital collection of Neandertal and modern human fossils which are housed at the Royal Belgian Institute of Natural Sciences (RBINS), to showcase the reconstructed Spy II Neandertal and to highlight Belgian scientific and cultural heritage, as well the current state of the art research in Belgium. The musculoskeletal software 'lhpFusionBox' used to build the Spy II Neandertal was also further adapted for paleoanthropological study. Alongside the digitised collection, an additional aim of the project was to make current knowledge on Neandertals more accessible to the general public by creating a website on Neandertals.

Conclusions

The virtual reconstruction of the Spy II Neandertal has been completed during the project using newly discovered and unpublished fossil material. All fossils have been digitised with photogrammetry and all bones of the Spy II reconstructed skeleton have been prepared for 3D printing . A detailed method has been created so that 3D non-contact moulds can easily be made by schools and other museums using low cost 3D printers. LhpFusionBox is better adapted to paleoanthropological needs with the development of automated functions, visual tools and biomechanical features. Finally, a website has been created which gives up to date knowledge on Neandertals using the digitised fossils created during the project.

Keywords

Neandertal, Virtual, Fossils, Reconstruction, LhpFusionBox

1. INTRODUCTION

The Spy Neandertals have been extensively studied by both national and international researchers since they were found in 1886. In 2004 there was a large multi-disciplinary project focusing on the reassessment of all the Spy fossils. Several bones of Spy I and the human collection were reattributed to the Neandertal skeleton Spy II, making it one of the more complete Neandertal skeletons in the fossil record. The aim of the Neandertal_3D BRAIN project was to utilise the existing digital collection of Neandertal and modern human fossils which are housed at the Royal Belgian Institute of Natural Sciences (RBINS), and to highlight Belgian scientific and cultural heritage, as well the current state of the art research in Belgium.

The project joined together teams and skills from the Flemish Vrije Universiteit Brussel (VUB) and the French [speaking] Université Libre de Bruxelles (ULB), the Federal Scientific Institution (FSI) of RBINS and a non-profit organisation from the Brussels Capital region Association pour la Diffusion de l'Information Archéologique (ADIA). There was also an International partner from France, Musée de l'Homme (MNHN). Members of the project came from the different disciplines of medicine, biomechanics, palaeontology, engineering, computer science and education and they worked together to highlight this important digital collection..

A main aim of the project was to showcase the virtual reconstruction of the Neandertal Spy II skeleton. The Spy II skeleton continued to be developed during the project with additional fossil material added and new fossil reconstructions done with members of the Neandertal_3D partners, the follow up committee and outside experts. The reconstructed 3D Spy II Neandertal and other Neandertal fossil specimens housed at RBINS have been digitised with photogrammetry, which was found to be the best method for 3D printing and all bones were subsequently prepared for 3D printing. A detailed method was created so that 3D non-contact moulds could easily be made by schools and other museums using low cost 3D printers. The idea of this work is that it would replace the classical cast system which have potential problems for the original fossils, where reproductions can be 2-5% smaller than the original.

The availability of the reconstructed Spy II skeleton is particularly important as there is no complete skeleton in the fossil record. A paper is in preparation on the reconstruction of the Spy II skeleton and once published – it will serve as a citation document and the entire reconstruction of the Spy II skeleton will be available upon application to the RBINS curator. The aim is that everyone will be able to have access to the skeleton and the fossils used to reconstruct the skeleton. This publication will serve to highlight the work of the federal institutions and the Flemish (VUB) and French (ULB) universities of Belgium and the digitised collection of Neandertal and modern human fossils.

The musculoskeletal software 'lhpFusionBox', which was previously developed by ULB, was the main software used to reconstruct the Spy II skeleton. The new development of the lhpFusionBox is now better adapted to paleoanthropological needs with automated functions, visual tools and biomechanical features being developed during the course of the project. The software is based on open source technologies and is freely available to use with a research agreement between the ULB and prospective researchers.

A final aim of the project was to make current knowledge on Neandertals and the entire digitised Neandertal collection (including the reconstructed Spy II skeleton) available to the general public. The project created an interactive website which will serve as an educational experience on Neandertals, who are often portrayed in the public as cavemen, stupid brutish and more ape like than modern humans. The website will seek to redress this balance and has up to date knowledge on Neandertals as well as showing the comparison between them and modern humans.

2. STATE OF THE ART AND OBJECTIVES

Human evolution not only fascinates both the media and the general public, it is also a key topic in Belgian primary and secondary school programs. The opening of the new Gallery of Human Evolution in RBINS in May 2015 showed the enormous interest that both scholars and families have for new and original presentations. Attractive pedagogic virtual and physical media are today essential to provide up-to date information and support to teachers. This kind of dissemination is of most interest to adults interested in the museum and also to children themselves who will grow up to know about different hominin specimens, (including the Neandertals).

The main objectives of this project were to showcase and utilise the digitised Neandertal and AMH Belgian fossils hosted by RBINS, with a special focus on the reconstructed Spy II Neandertal. This was done by developing new services, tools and operations to ultimately allow not only teachers and children but also different users groups to be able to access and valorise this unique heritage. The following four areas were developed:

1. Science: Adaptation and enhancement of the musculo-skeletal software 'lhpFusionBox' for palaeoanthropology purposes. The improvement of the lhpFusionBox software enabled the comparison of modern humans and Neandertals. ULB previously developed the lhpFusionBox software for the improvement of healthcare for medical patients in the framework of European Commission projects. It is a state of the art musculoskeletal system with the aim of being used as a multidisciplinary platform for data processing, model building and reporting on the dynamic behaviour of relevant physiological human parameters. However, during the project the software was further adapted to paleoanthropological needs to include a better visualisation of textured objects, automated measuring tools and biomechanical analysis tools.

2. Open Science & Cultural Heritage: Adaptation and sharing of the Human remains 3D models allowing the virtual observation and production of non-contact casts. The models created within the project will be freely available and downloadable to everyone who has an interest in them, i.e. the general public, schools, museums, etc. This is of advantage to all user groups.

3. Gaming: Integration of the reconstructed Spy II Neandertal model into the applications of educational games for children, serious gaming and the Neandertal website. ULB and VUB have previously collaborated in the development of 'serious gaming' applications in the framework of two recent projects. A key element in physical rehabilitation is motivation to continue to perform physical rehabilitation exercises. Serious games are rehabilitation schemes used for the treatment of movement disorders and help motivate patients to do their exercises.

4. Equal opportunities: A public website was created during the project using the Neandertal models and 3D animation and AMH fossils hosted by RBINS. This website will serve to educate the public on current scientific research and thinking on Neandertals and Human evolution. The website will also serve as an educative experience on Neandertals highlighting the state of the art research that is now being done by researchers in Belgium.

The project outcome can also be seen as advantageous in different areas. For the scientific and research community, the freely available bones will be an import resource for (palaeo)anthropology and other disciplines such as forensic science. One of the biggest difficulties in studying Neandertal and other fossil hominin bones is the availability of specimens. This project takes the availability a step

further by offering a fully scaled 3D Neandertal skeleton freely available under the CC licence CC BY ND NC which will be available once the article on the reconstruction is published. The software development of LhpFusionBox is also a very important result and offers to the scientific community an easy but very powerful Open Source software allowing the visualisation and the study of 3D digital collection objects with or without their texture.

The creation of the Neandertal website portrays Neandertals in a new light. The latest state of the art research will serve to demonstrate that Neandertals are not so different from modern humans. The creation of a free website gives access to digital heritage to a broad spectrum of people who may not typically visit museums. Most people have access to a computer and the internet. However, they will not necessarily spend money on transport to or entry fee to visit a museum. Conversely, more visits to the to the website will also lead to more visits to the Royal Belgian Institute of Natural Sciences as it will serve to show the reconstructed Neandertal skeleton which is currently housed in RBINS.

The use of tablets and the development of games with an educational purpose can also be extended to different cultural heritage collections. Many primary school children seek information online and there is a clear trend towards consulting social media, i.e. vlogs (video blogs) and mobile games. We identify a huge potential in educating children on issues relative to cultural heritage, such as informing them on fossils or extinct species, by means of informative computer games. The so-called serious games also have educational/informative purposes with fun and entertainment.

The Neandertal and AMH fossil collections are an important digital collection. However, the project could also serve as an example of what to do with other 3D digital heritage collections. The use of tools to accompany the fossils and perform both traditional measurements and new avenues of research is a smart and exciting realisation of cultural heritage. The project further demonstrates the need for a 3D digital collection in conjunction with a physical collection at the Federal institutions by the following:

1. 3D digitisation creates a permanent record of the object,
2. helps preserve the object,
3. help in the curation and restoration of the object,
4. help to improve the valorisation of the object both from the scientific point of view but also the viewpoint from education and the broader public.

The creation and the valorisation of a 3D digital collection can also play a role in difficulties involved in repatriation as they provide an alternative by giving access to the scientific information to scientists from the countries of origin. The 3D printing of physical replica also allows Museums from the countries of origin to display high resolution replicas based on this non-contact digitisation.

3. SCIENTIFIC RESULTS AND RECOMMENDATIONS

The project was divided into eight different workpackages. We combined the sections 3. Methodology and 4. Scientific results and recommendations as is allowed in the guidelines. We first detail the tasks that were specified in the project and then detail the methods used to carry out these tasks and the results achieved:

WP 1 PROJECT MANAGEMENT – WPL: ULB/RBINS

Task 1.1 Project Coordination – TL: ULB

- Overall project coordination including ensuring the initial work plan is respected, chairing the internal partners meetings (fortnightly meetings between ULB and RBINS, monthly meetings between members of Scientific Committee), follow up committee meetings and anticipating delays and proposing alternatives to the project to the Scientific Committee for discussion

- Liaison between BELSPO services and the project partners. Ensuring effective communication of administrative tasks and issues within the partners.

- Ensure proper communication and coordination between partners, WPs, the follow up committee and other external contacts.

Activities realized and results achieved

Regular project meetings between ULB, RBINS, VUB and ADIA and individual members of these institutions have been held depending on the needs of the project tasks. There has been also regular communication between ULB, RBINS, VUB and ADIA with a view to improving the lhpFusionBox software. During the prolongation period there has been continued meetings and work between ADIA, RBINS, VUB and ULB. The follow up committee meetings have taken place as scheduled and reasons for delays have been discussed with the follow up committee. The most important meeting minutes are detailed on the website.

http://collections.naturalsciences.be/ssh-projects/projects/neanderthal-3d/project/working-folder/meetings

Activities were monitored through active discussions between partners. Next to many informal meetings, formal meetings have been organised:

Kick-off meeting on September 12^{t}2017.

User requirements were discussed on September 18th 2017.

Game specifications were discussed on May 4th 2018.

Development specifications and project progresses were discussed on February 26th 2019.

Action points were discussed on February 28th 2018.

The 1st follow-up committee has been held on April 24th 2018.

Final game scenario and development were written on April 8th 2019.

The 2nd follow-up committee has been held on June 21st 2019.

Task 1.2 Project Reporting – TL: RBINS

- Creation and maintenance of the website of the project on the RBINS Scientific Service Heritage Plone server.

- Production and consolidation of periodic external reports. Work plan maintenance, monitoring of progress, timely production and adherence to quality procedures to deliver projects output.

- Production and consolidation of cost-statements

Activities realized and results achieved

The creation of the website of the project on the RBINS Scientific Service Heritage Plone server was set up early in the project. All members of the project have access to the server with a unique user name and password. The members of the follow up committee also have access to the project website.

http://collections.naturalsciences.be/ssh-projects/projects/neanderthal-3d

A production and consolidation of cost-statements took place between Belspo and the Financial Department of ULB.

WP 2 REVIEWING AND ANALYSIS PACKAGE: LHPFUSIONBOX – WPL: RBINS

This workpackage will focus on a review of the current literature on measurements, analysis and visualisation tools and will identify the tools necessary for effective palaeoanthropological study.

Task 2.1 Review of the literature – TL: RBINS

This task will focus on an exhaustive review of the literature related to available digital tools and in existing software to find out what is currently available and what is missing in the palaeoanthropological field in term of measurements, analysis of fossil hominids and visualisation tools.

Activities realized and results achieved

An exhaustive review of the literature was undertaken. The literature focused on paleoanthropology and how this has changed from the use of traditional tools in paleoanthropology to utilise digital tools. Digitisation is necessary for museum collections as it is a back up for objects which are often fragile and unique, can be shared with other researchers around the world and can be used to create a virtual museum. In addition to this, the creation of a digital object gives accessibility throughout the whole object and means that tools can be developed to perform measurements not possible on the physical object. The literature review then focused on what digital tools are currently available in which software and what is needed for paeloanthropology. This formed the basis of Task 2.2 (Definition of User Specification).

The literature review can be found on the website of the project.
http://collections.naturalsciences.be/ssh-projects/projects/neanderthal-3d/project/deliveries/task-2-1-literature-review/at_download/file

Task 2.2 Definition of User Specification – TL: RBINS

Digital tools for viewing and analysis of virtual objects (including taking both simple and complex measurements) are crucial for scientists and curators. However, integrated Open Source analysis tools for this purpose are mostly lacking. The partners in this consortium previously developed a specific analysis tool for biomedical applications called lhpFusionBox. They demonstrated that this tool can be tailored partially towards the needs of palaeoanthropology or other disciplines (Chapman et al. 2013). In this WP, further conceptual and software development will be planned to extend the lhpFusionBox software towards the current needs of palaeoanthropologists working with fossil remains and digital objects. RBINS will work closely with MHNH to define the analysis and visual tools required for this cultural heritage domain. Members of the follow up committee and contacts from the International networks of the partners will also be invited to define the required tools.
This task deliverable will be a detailed and well-documented document that will describe user needs and will be utilised in Task 2.3 to define the technical specifications that will guide the development of the novel methodologies and scientific tools requested.

Activities realized and results achieved

Detailed user specification guides have been drawn up based on the literature review completed in task 2.1.

2.2.1 Scale new dataset
(the bug should be fixed when scaling datasets – for use in fossil hominid reconstruction).

2.2.2 New format
(museums often use digital photogrammetry resulting in OBJ and PLY files. These files should be able to be exported in lhpFusionBox. Also animation files should also be able to be exported from lhpFusionBox in the format of fbx or blend).

2.2.3. Measurements
(data should be able to be exported easily so that 2D and 3D measurements can be compared with other software systems, a script to automate measurements should be developed and the possibility of doing a digital osteometric board should be investigated)

2.2.4 Centre line of an object
(ULB previously developed a method to analyse ribs using best fitting ellipses of external contours of the cross section areas, created from the centre line of the rib. This method is of interest to palaeoanthropologists as they allow the quantification and analysis of bones in 3D space which are not possible through physical measurements (i.e. the method seeks to analyse the curvatures of the bone which is difficult to do in physical measurements).

2.2.5. Parametric surfaces and muscle wrapping.
(The coordinator ULB previously developed three-dimensional (3D) quadric surface fitting in particular bones (humerus, femur, pelvis, tibia)(Sholukha et al., 2011; Chapman et al., 2015). Three-dimensional quadric surface fitting is the fitting of 3D shapes (i.e. ellipsoids, spheres, one sheet hyperboloid and two sheets hyperboloid) onto bones to accurately mathematically model the bone and to enable direct comparisons with other similar bones. This is a useful tool for anthropologists as you could analyse positions of quadric surfaces and also compare measurements of the surfaces with other bones. Once parametric surfaces have been created then a new system of muscle wrapping should be developed to allow biomechanical analysis of fossil hominids.)
The detailed user guides can be found on the website of the project.
http://collections.naturalsciences.be/ssh-projects/projects/neanderthal-3d/project/deliveries

Task 2.3. Definition of Technical Specification – TL: VUB

Task 2.2 will lead to a document detailing the specifications of the tools required. This document will then be used by the partners VUB and ULB to write the technical specifications needed to develop further software code based on the user requirements. Software will be implemented in C++, Phyton and C#. Based on current needs, the software will be developed in four domains and are described in separate tasks below (3.1, 3.2, 3.3 and 3.4).

Activities realized and results achieved

Detailed user specification guides were drawn up based on the literature review completed in task 2.1. For task 2.3, the user specification guides were taken and divided into different tasks and each task had (1) the expected OUTPUT data from new operations, (2) the methods and algorithms to produce these results, (3) user interface and actions required to inject INPUT data into algorithms. Priorities were given to the tasks according to the need of the project.

The detailed guides can be found on the website of the project: http://collections.naturalsciences.be/ssh-projects/projects/neanderthal-3d/project/deliveries

WP 3 METHODOLOGICAL AND IT DEVELOPMENT OF (PALAEO)ANTHROPOLOGICAL TOOLS - WPL: ULB

Task 3.1. Creation of practical field operation – TL: VUB

There are many independent operations that exist in the current version of the lhpFusionBox but they were aimed towards an engineering public, which is similar to other modelling software (OpenSim, AnyBody, LifeMod). In previous projects and studies it was noted that many of the routine operations for anthropologists and archaeologists are composed of a long sequence of simple independent operations in lhpFusionBox, making the use of the current version very repetitive and prone to errors due to operator fatigue from having to frequently repeat the same sequences of operations. Task 2.2. will identify the most difficult and complex operations. This task will then concentrate on creating a set of practical script-like operations directly usable in the field by palaeoanthropologists and archaeologists, mainly by aggregating already existing operations into new ones. A potential strategy could be to implement a scripting or macro mechanism to simplify or repeat complex operations. This approach has clear advantages over developing specific operations for each user domain as it allows the domain experts to extend the functionality themselves, and to perform scientific operations in an as automated manner as possible.

Activities realized and results achieved

The work was almost complete in year one. Year 2 and during the extension focused on bug fixing, in addition to the creation of automated measurements and angles.

Task 3.2. Development and implementation of novel measurement tools in lhpFusionBox – TL: ULB

In task 2.2. RBINS will work together with the MHNH to identify measurements to be implemented into lhpFusionBox which will be better suited to (palaeo)anthropological and forensic sciences requirements, and the analysis of the digitised (fossil) bones. This will start with the analysis of the physical anthropologist Martin's (Martin 1928) measurements (as they are measurements which are most often used in (palaeo)anthropology. This will ensure that analytical studies produced in the virtual environment can be compared to previous similar research and will therefore be of the most interest to other researchers. RBINS will then work with ULB and VUB to analyse the suitability of implementing already prototyped methods into lhpFusionBox, such as the automated modelling of

joint and bone morphology using primitive objects (such as sphere, ellipse, quadric surfaces, etc. as detailed in the methods).

Activities realized and results achieved

During year 2, a first version of a filter for quadric surfaces fitting was implemented into the lhpFusionBox. This version includes ellipsoid (as one case of quadrics) and take as input, 3D surfaces, parametric surfaces or, point clouds. The choice of ellipsoids was driven by the fact that it is the most common fitted quadric for joints. Primary validation was done by taken as input a well know ellipse or its vertices and applying the filter to it. The validation is successful when the filter finds the parameters of the used ellipsoid. A filter that allows to extract region of interest ROI from a 3D surface was also implemented. This allows to easily steer the software to only fit a quadratic surface on a subset of a larger point cloud (as shown in figure 1).

This activity continued during the project prolongation and the fitting filter has been extended to more quadrics such as hyperboloids as some specific joints will be better modelled by these quadrics. Task 3.2 has been fully realized.

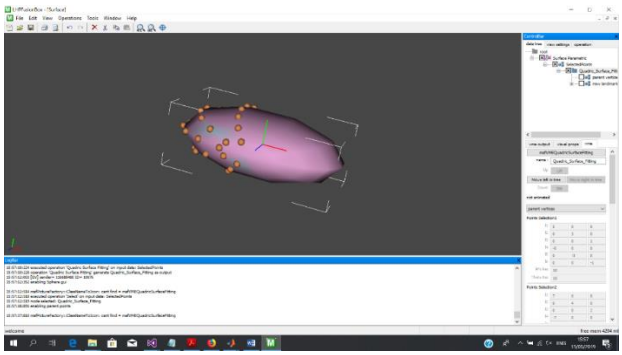


Figure 1: Fitting surface filter applied on points from an initial ellipsoid. The result in pink is superimposed with the initial ellipsoid in green.

Task 3.3. Development of new import formats and visualisation of textured objects in lhpFusionBox – TL: VUB

One of the limitations of the actual version of lhpFusionBox is that the software is not able to display 3D models with a colour texture in the same way as other software viewers such as Meshscan. The visualisation of Cultural Heritage objects is thus limited. lhpFusionBox will be adapted to visualise and allow the importation of a textured file such as PLY and/or OBJ files. This will be defined according to task 2.2 and also according to compatibility with other software. This task will also examine how to manage visualisation and analysis of multispectral acquisitions which would be of significant use to other digitised cultural heritage collections. lhpFusionBox is able to align multiple models in the same space. It is thus possible in theory to use the software to display multispectral acquisitions of the same object and to switch from one view to another using the same reference system and one set of landmarks. This will enable the comparison of different acquisitions of the models and enable users to evaluate differences between the models.

Activities realized and results achieved

The import of textured files was implemented, together with the extension of the rendering pipeline. A new feature is added to allow saving and exporting 3D model with the texture. The output file can

be in the format .wrl or an .obj with texture and can be imported in other software or with online platforms such as sketchfab and blender. Task 3.3 has been fully realized.

Task 3.4 Development of wrapping method – TL: ULB

The project aims to develop a novel methodology of muscle wrapping around joints. This is justified by the fact it is still an unsolved challenging topic in the musculoskeletal modelling field, and by extension in (palaeo)anthropology. A more effective wrapping methodology that is coherent with real musculoskeletal behaviour would be of high value and give more accurate insight into musculoskeletal physiology compared to current tools and would allow an accurate modelling of muscular movement of fossil individuals. A feasibility study on muscle wrapping was previously performed on the reconstructed Spy II skeleton and despite the fact that preliminary results were promising; it also demonstrated the limits of current methods and the need to develop more optimal musculoskeletal wrapping tools and models.

Activities realized and results achieved

During the second year, a major activity for Task 3.4 was around investigation of Stavness et al. (2012) and A.Scholz. (2015) approach parameters to get robust behaviour of solution using different combination of quadric surfaces (as obstacles) and parameters of numerical methods (e.g. nonlinear algebraic system roots and ODE methods solution). Current software implementation allows analysis of multiple muscle fibres length with predefined motion of origin end insertion and moving obstacles (including change of obstacle size). Based on collision detection between fibre and obstacles the size of the nonlinear algebraic system equations could be reduced which is speed up solution up to maximum in case of no contact between fibre and obstacle. Figure 2 contain results of wrapping modeling for multiple obstacles, including mutiple fibres and simulating path lift-off and touchdown based on collision detection (A.Scholz. 2015, Figure 3) between line and explicitly defined QS (using signed distance "d"). Current MATLAB@ implementation with test examples is available for conversion and implementation in lhpFusionBox.

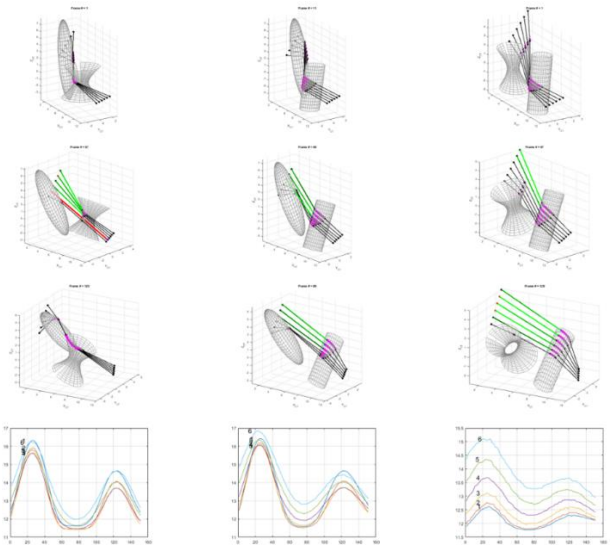


Figure 2. Three examples of muscle wrapping simulation using combinations of quadric surface as obstacles. Each muscle approximated by six lines with moving origin end insertion (black dots). Quadric surfaces pose (six DoFs) and size could be adjusted for each frame. Black lines correspond to strait lines tangential to obstacles. Magenta lines correspond to geodesic ones smoothly connected to black lines. Green coloured lines indicate contactless with one obstacle. Red line (left column, second raw) indicate contactless with both obstacles. For each column last line contains plot of the six fibre length.

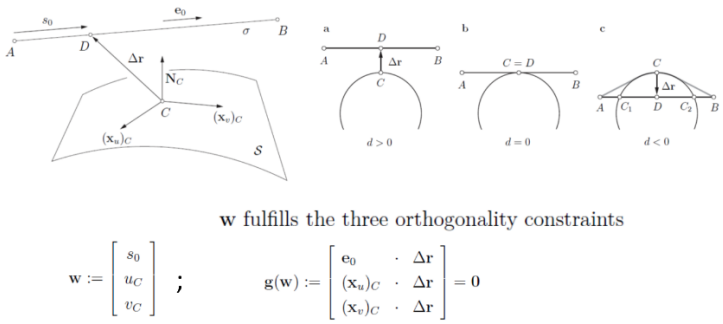


Figure 3. Nonlinear system of three equations g(w) = 0 (orthogonality conditions for shortest line between fibre and QS) for detection fibre path lift-off (d>0) and touchdown (d<0) for collision detection between line and explicitly defined QS (A.Scholz. 2015).

A first version of the wrapping filter is implemented into lhpFusionBox based on the MATLAB@ implementation. This version supports just ellipsoids as wrapping surfaces. The filter takes as input the parameters of the quadric and four points that will make the lines modelling the fibres.

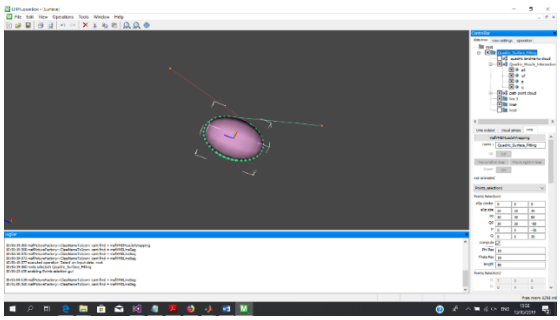


Figure 4: Computing a wrapping line directly in LhpFusionBox

Extensions to other quadrics (ellipsoids, hyperboloids H1, hyperboloids H2, cylinders) have been made. Temporal data with evolving intersection between the line and the quadric were tested with success. The filter supports a wrapping line around two different quadrics which is sufficient in our applications. The final GUI allows the user, to define the insertion points defining the wrapping line and the quadrics it could wrap around. Others parameters such as contact points are computed automatically.

<u>References.</u>

Stavness, I., Sherman, M., Delp, S., 2012. A General Approach to Muscle Wrapping Over Multiple Surfaces. Am. Soc. Biomech. Conf.

A.Scholz. (2015) Fast Differential-Geometric Methods for Continuous Muscle Wrapping Over Multiple General Surfaces, PhD.

Task 3.5 User testing of new tools implemented in lhpFusionBox – TL: RBINS

In order to maximise the fit between the developed software modules and the requirements from the domain(s), a user-centred design methodology is adopted in this WP. It entails continuous testing by the actual users, not only with respect to assessing technical correctness, but also with respect to relevancy of the proposed methods and the ease of user interactions. RBINS will also invite MHNH, members of the follow up committee and contacts from their International network to assist with testing the software. VUB, ULB and RBINS will then regularly meet to discuss the evaluation of newly incorporated features. A bug tracking system will be established by VUB to keep track of the various bugs and feature requests. In order to ease user testing and software updates, a web-based software auto updating mechanism will be put in place as well.

Activities realized and results achieved

Regular meetings have been held between VUB, ULB and RBINS to evaluate and discuss the newly incorporated features. RBINS and ULB have worked on new iterations of the software with different updates to test the new features to make sure that there are no bugs and that the new updates work as expected. This has involved working closely with VUB and continuous contact has been maintained via email and telephone, although all project members have also met face to face at different intervals. Each time a new development has been made by VUB, then it has been tested at RBINS. This has helped to check for bugs and other problems which arise when changes to the software code is made.

Members of RBINS have also either joined existing projects or have created new projects which have the purpose of testing the new software tools, which at the same time strengthens and reinforces new and existing collaborations. New features of the software have been shown internally to students and staff of ULB and RBINS and the University of Gent, to follow up committee members and to international conferences where we have stated that the software is available to test in specific cases (See Dissemination and publications 5 and 6).

The new script-like operation developed in task 3.1 is completed and allows users to automatically create angle or distance meters. The feature has been tested with students and staff from RBINS. A PhD student, Alexandra Boucherie from Université Libre de Bruxelles, tested the script-like operation to automatically create angle or distance meters on a series of skulls and has given two presentations on this subject at a national seminar and international conference (see Dissemination and publications 5 and 6). Caroline Polet from RBINS is the supervisor of Alexandra Boucherie and Tara Chapman from RBINS is also working with Alexandra to test the repeatability of the measures.

This script like operation has also been tested in the context of the projet IRAM (Interdisciplinary Research on Andean Mummies http://www.iram-project.be/). Caroline Polet and Tara Chapman of RBINS are part of this project which also includes the Fonds Jean-Jacques Comhaire - Fondation Roi Baudouin, Musées royaux d'Art et d'Histoire (MRAH) and Cliniques universitaires Saint-Luc (CUSL) A script was set up to automate and analyse the measures on the pelvis of the Precolumbian mummies housed at MRAH to determine sex (DSP measurements). The results of this research was presented at an International conference in January 2019 (see Dissemination 5) and a paper has been published on this work (see publications 6).

RBINS is also working on the Homo naledi gait project in collaboration with International researchers from different institutions in the United States, South Africa and Italy (Zach Throckmorton, Steven Churchill, Damiano Marchi, Bernhard Zipfel, Christopher Walker, John Hawks, Lee Berger, Jeremy deSilva). The reconstruction of the Homo naledi skeleton was used as a test case for the Neandertal_3D project in addition to the Neandertal skeleton with the task of scaling objects (task 2.3.1) . A paper is in submission with this work (Chapman, T., Marchi, D., Walker, C., Vereecke, E., Churchill, S.E.,

*Congdon, K.A., DeSilva, J., Zipfel, B., Hawks, J., Van Sint Jan, S., Sholukha, V., Harcourt-Smith, W., Berger, L.R., Throckmorton, Z., **in** submission. Gait kinematics of Homo naledi).*

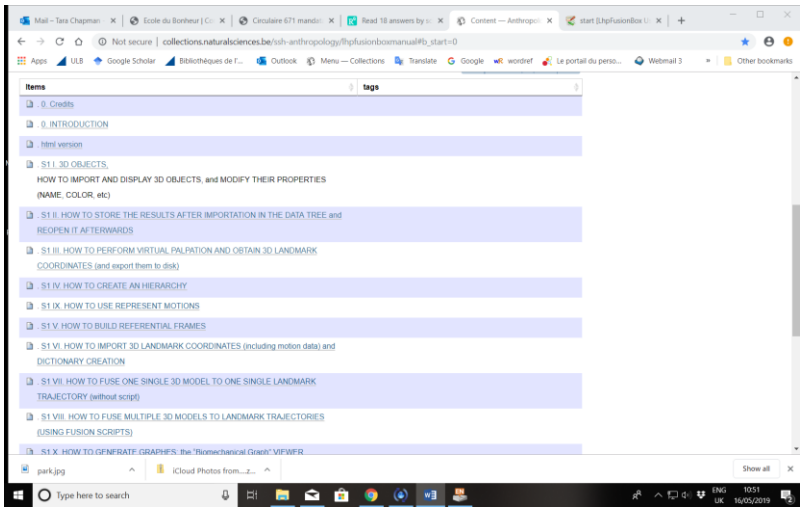
A first version of the software with all latest features was shown to the follow up committee members in the meeting on 24th April 2018 and on the 21st June 2019 who were able to test and use the new features developed in the past year. RBINS has also worked with individual members of the Neandertal_3D project Follow Up Committee. A meeting was held with Tara Chapman and the follow up committee member Daniel Garcia Martinez in Paris in January at the 1844èmes journée de la SAP at the Musée de l'Homme where Tara Chapman demonstrated the new software features. Alon Barosh and Ella Been (external consultants) and Daniel Garcia Martinez worked on the new features with Tara Chapman on reconstructing a new thorax for the Neandertal. The software has also been shown to students and staff of ULB, the University of Kent, the University of Gent and international conferences (see task 7.1).

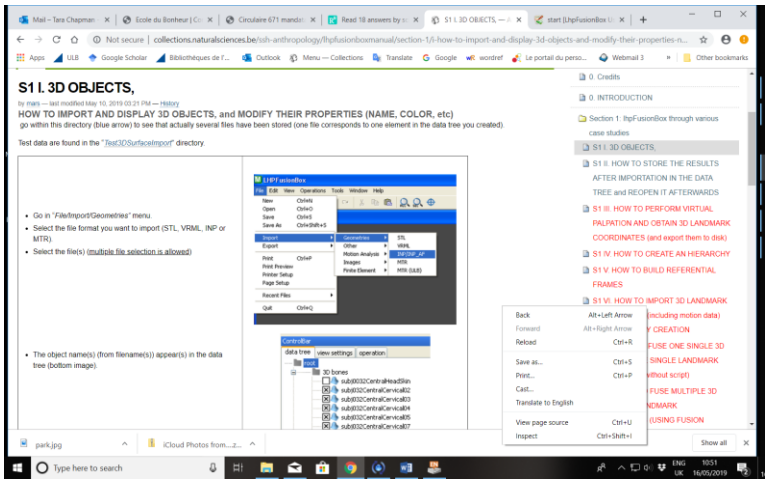
Task 3.6 Documentation and training material for lhpFusionBox – TL: RBINS/ULB

In line with the rationale behind all the other work in this WP, we want to provide the domain users with all possible help to be able to use the software package as easily as possible. A first version of a user manual for the current version of lhpFusionBox is currently maintained by ULB. This document will be extended with new features to include the new aspects of lhpFusionBox. The guide will also include appropriate references for biomechanical analyses performed. VUB will ensure the user manual is easily accessible from within the software itself. The online manual will also be available on the website of the project hosted by RBINS.

<u>Activities realized and results achieved</u>

A preliminary website for lhpFusionBox was created at http://www.lhpfusionbox.org, which currently is only a draft version. Following inter-partner discussions, it was decided to have an online lhpFusionBox manual which can be continually updated. Several tests were performed to see what was the best way to upload the document and also maintain the document online. Originally it was going to be placed on a wiki on a separate website however, this did not effectively reproduce the correct effect of the manual (http://users.lhpfusionbox.org/doku.php) . It was therefore decided this will be placed on the RBINS website (http://collections.naturalsciences.be/ssh-anthropology/lhpfusionboxmanual) and the user will need to identify to get access to this part. See several screenshots of how the manual will look).





The website has not been fully produced because the work required to perform the work has been underestimated. However all documentation and training materials have been produced and can be distributed to users through various channels (electronic transfers). As such Task 3.6 has been fulfilled.

WP4 NON-CONTACT REPRODUCTION OF CULTURAL HERITAGE OBJECTS – WPL: RBINS

Current developments in scanning and 3D printing technologies enables the production of high resolution 3D objects (< 50 µm) based on the virtual model. Non-contact production is a unique opportunity to create a high resolution duplication without using casting products (silicone and polyurethane resin) which can damage the original object and/or are toxic for users. Another limitation of classical moulding reproduction is the smaller size of the replica (reproductions can be up to 2% smaller). The 3D digitisation/3D printing offers a great potential for scientific purpose, curation aspects and valorisation. This project will use the RBINS fossil hominids collection to evaluate the potential of this new method of reproduction for the different applications and establish best practices which can be (re)used for other collections. In the case of fossil hominids, 3D digitisation also provides a virtual backup of the specimen before destructive sampling (e.g. for radiocarbon dating or palaeogenomic and isotopic studies). The non-contact 3D reproduction opens up new opportunities for studying, learning about and disseminating Cultural Heritage objects, including human remains.

Task 4.1 Evaluation of the virtual reproduction of physical objects – TL: RBINS

In this task, RBINS and MNHN will compare the level of detail and the resolution/accuracy of the digital reproduction in comparison with the classical moulding protocol. Best practices will be established for the use of this new approach in the routine activities of the RBINS and other Federal Scientific Institutions. This will include following the evolution of the physical object through time and different preservation conditions and making 3D reproductions before restoration or destructive sampling.

<u>Activities realized and results achieved</u>

Several activities took place looking at the accuracy of the digital reproduction in comparison with the classical moulding protocol. In addition to the activities with members of the AGORA project detailed in task 4.1, other projects analysed the differences between casts, originals and digitised specimens. A joint project was set up with ULB and RBINS to check the accuracy of casts using the Le Moustier Neandertal. This work has been the subject of a publication (see publications 6).

The Le Moustier Neandertal is an adolescent invididual and as such is an important fossil specimen which can look at questions such as ontology and growth of an individual. There is a difficult history with Le Moustier 1 as it was sold to the Musée de Berlin and was largely destroyed at the end of the Second World War, with only the skull remaining. Before the skeleton was destroyed there was a series of casts taken on the skeleton. These casts are important because Moustier 1 is an adolescent somewhere between 9 and 14 years of age. However, as it is only the casts that are available, it is important to know how accurate the casts are. The first aspect of the study on Le Moustier examined the differences between the reported measurements on the original bones and the measurements on the casts. The second aspect examined the differences between the casts and the digitisation of the casts.

Given that the original remains were destroyed by fire, these plaster casts are an important teaching and scientific tool. The remains are clearly Neandertal and as juvenile remains they are an important addition to the Neandertal fossil collection. There is no difference between the published measurements on the original bones and the casts at LABO and the Natural History Museum, highlighting that these casts are (in measurements at least) a faithful reproduction of the original. However, there are some considerations and measurements can only be seen as estimates given that for the long bones in particular, they seem to be in a large part reconstructed.

There are difficulties in using cast material as a source of metric data. However, due to the disappearance of the original bones, the possession of original casts is a major scientific and didactic asset despite their imperfection, especially since the post-cranial remains of Moustier have hardly been the subject of exhaustive descriptions with the main documents being Hauser, (1909) on the original bones and Thompson and Nelson (2005) on the casts. The casts seem to be relatively accurate in terms of size of the original fossils. The CT scan enables 3D models of the Neandertal bones which are now freely available. We feel that digitised remains are entirely viable alternatives (given the lack of statistical significance between the originals and the digitised LABO casts). However, consideration needs to be given to the lack of details present in these plaster casts. The way measurements are taken in 3D also needs to be improved so that measurements on digitised specimens can be taken in the same way as traditional measurements on physical bones and this was addressed in Workpackage 2 of the Neandertal_3D project as detailed above.

The analysis of the virtual reproduction of physical objects continued during the prolongation of the project and has extended past the project. Two studies have been undertaken with T. Chapman (RBINS) and Alexandra Boucherie on a series of skulls. A series of measurements were taken on these skulls both virtually in lhpFusionBox and physically to determine if it is possible to accurately sex the skulls using specific landmarks and to look at the differences in measurements between physical objects and those objects digitised. The study was completed during the prolongation of the project and a paper is in preparation on this. The second study is with Alexandra Boucherie, Daniel Garcia Martinez (of the follow up committee) and will look at the geometric morphometric analysis of the skulls to look at the advantages of working with digitised objects. An article is currently in submission.

1st Study – T. Chapman, A. Boucherie (in preparation)

- *Comparing physical and virtual metrical variables on the skull base*
- *100 skulls (50 females, 50 males) have been digitalized with a surface scanner NextEngine*
- *Theses skulls are coming from seven identified osteological collections from Europe (Belgium, France, Switzerland and Portugal). Age and sex are known for each individual. Among these collections, there are two identified collections of the Royal Belgian Institute of Natural Sciences (Schoten and Châtelet).*

- *A set of several measurements (ca. 70) were taken with a sliding calliper on the skull base (occipital and temporal bones) of these individuals, they represent the physical variables. Another observer took the same variables a second time.*

- *Virtual metrical variables were taken on this same sample of skulls with the software LhpFusionbox.*

- *To evaluate the measurement errors entailed by the virtual acquisition, a sub-sample of 30 skulls (15 females, 15 males) were measured virtually a second time by the project holder (A.B.) and by an additional experienced observer (T.C.). An intraclass correlation coefficient and both absolute and relative technical errors were calculated.*

- *Results showed that in intraobserver only one measurement is not repeatable. This variable is also not repeatable physically due to the inconstant nature of one landmark. The absolute and relative technical error in physical and virtual are quite similar, in the same range.*

- *In interobserver, seven measurements taken virtually are not reproducible. They are the same nonreproducible measurements than the ones taken physically except one variable that is based on a projection line. The absolute and relative technical error for virtual measurements are slightly higher than for the physical ones.*

- *As regards sexual dimorphism, the main goal of the research of the project holder is to apply the predictive models for sex estimation developed on physical measurements on the set of virtual variables to see if virtual models are reliable enough to replace in some methodological studies real skulls, especially when individuals of known-age and sex are not easily accessible.*

2nd Study – T. Chapman, A. Boucherie, D. Garcia-Martinez (published – see publications 6)

- *Exploring sexual dimorphism of the skull base through geometric morphometrics*

- *A sub-sample of 30 (15 females, 15 males from 25 to 93 years) adult individuals was selected for this analysis (maximum 50 can be included).*

- *The objective is to characterize the sexual dimorphism of shape and size of both areas of the skull base, i.e. occipital and temporals bones (that can be considered as two functional matrices).*

- *The use of geometric morphometrics will be beneficial in order to identify the sexual dimorphism existing in both areas in terms of pure shape and to evaluate potential allometric parts.*

- *For now, a set of 3D landmarks and semilandmarks were digitalized on the virtual skulls with the software Viewbox. The use of geometric morphometrics allow analysing curve, for example the curve forming the foramen magnum and the prominence formed by the mastoid process.*

- *Then, sexual dimorphism will be characterized on these two separate cranial areas through statistical analyses including PCA and discriminant functions (permutation tests for example) using the software MorphoJ.*

The Spy fossils were digitised in different ways and printing tests were performed to analyse which digitisation method produces the best results. A calcaneus was digitised using different methods and then 3D printed to see which digitisation method gave the best details. It was found that photogrammetry produced the most detailed 3D printed model. This study enabled us to make the

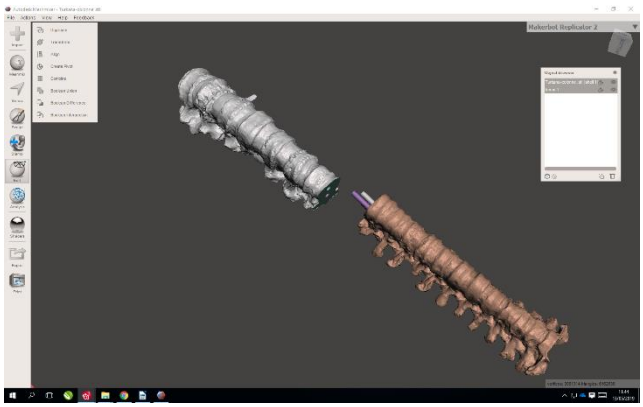
decision to release the Spy fossils which were digitised using photogrammetry as they gave the most detail.

Task 4.2 Preparing the 3D models for an easy and accurate 3D printing – TL: RBINS

- ADIA and RBINS will examine the digitised fossils in the collection and decide which fossils have the most priority to be placed on the website and corrected for 3D printing
- The models will be evaluated and corrected with the open source software GOM Inspect and Meshmixer to insure that there are no errors in the models.
- Each 3D model will then be printed in order to ensure that no problem occurs during the 3D printing.

All models have been chosen from the museums collection and placed on the Sketchfab website (see task 4.3 below for further details). This also included individual models of the Spy II reconstructed skeleton. These models have been prepared for 3D printing with GOM Inspect and Meshmixer and the whole skeleton has already been printed. For the other fossils, all photogrammetry models are ready for 3D printing and tests were made on some of the models.

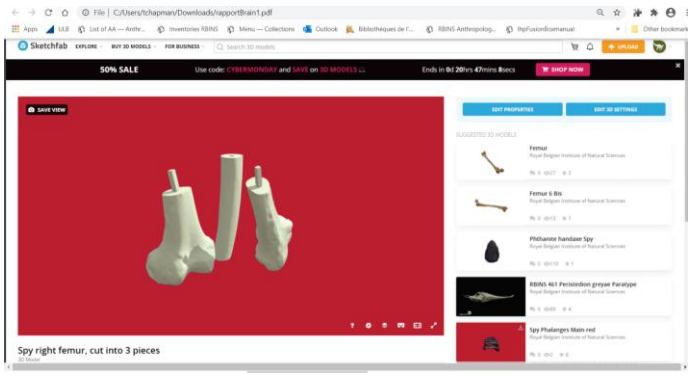
ADIA performed printing tests with two "Ultimaker" 3D printer models from two different generations, the early 'Ultimaker' and the more recent 'Ultimaker 2+ extended'. More and more schools now have 3D printers. As part of this project, we wanted to make virtual 3D models of fossil hominin bones available to these schools for their educational activities. To this end, printing tests have been performed with two "Ultimaker" 3D printer models from two different generations, the early 'Ultimaker' and the more recent 'Ultimaker 2+ extended'. The main difference between the two printers being support management. On the first model, the supports of the pieces left visible traces on the printed object, whereas the second does not leave any traces so this is clearly the better 3D model to use. In general, small pieces could be printed correctly. However, the printing of large pieces requires more attention: the impression of a complete skull, for example, takes several days. The risk of printing accidents is therefore greater with large format pieces. In addition, some very long parts such as femurs cannot be printed by a standard printer. It was for these two reasons that a system was devised (Mortice and tenon joint – see below) to cut the virtual models in several pieces and to design a system to enable pieces to be joined together after printing. Meshmixer (http://www.meshmixer.com/) is a free software programme which enabled this work to be done.

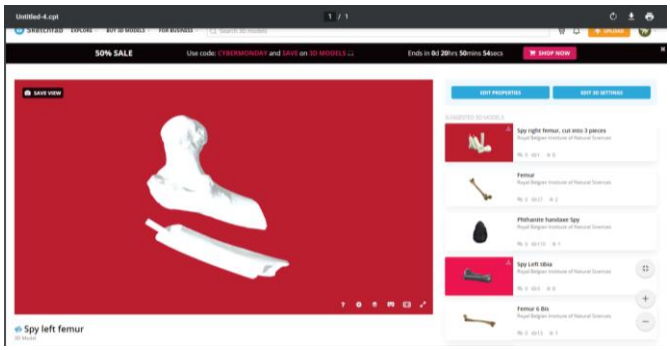


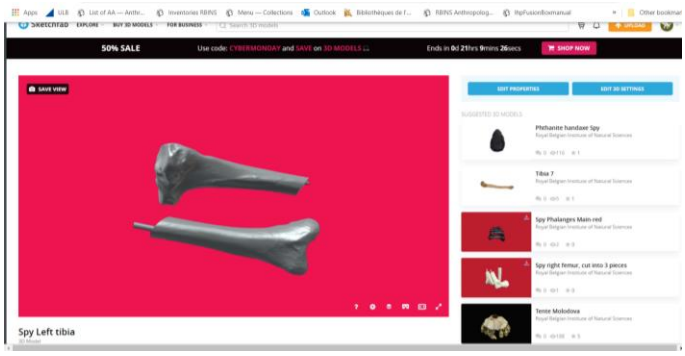
In this way, "kit" models or entire models can be made available to schools, regardless of the printer model they have. It is also possible to have the models printed by private companies.

Please see http://collections.naturalsciences.be/ssh-projects/projects/neanderthal-3d/project/deliveries/task-4-2-preparing-the-3d-models-for-an-easy-and-accurate-3d-printing/view for a detailed methodology on how to cut the bones and create a mortice and tenon joint. A test was performed on Turkana boy

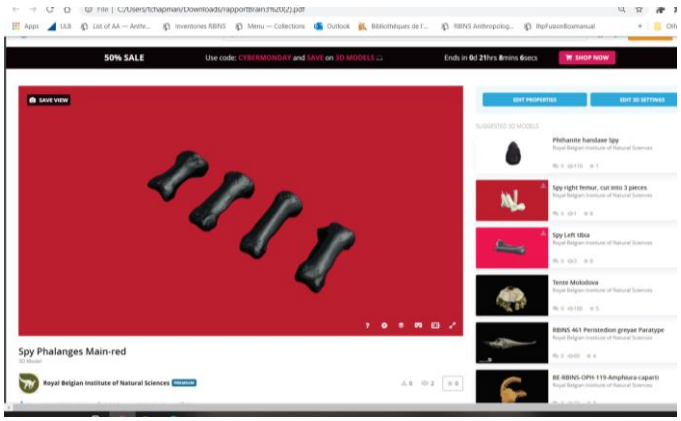
The larger bones of Spy II (left and right femur and left tibia) were then created in the same way and are now available both as the complete bone and also as a cut bone with this system (see below the cut bones which are in Sketchfab).







The models are ready and available on sketchfab. They will be released in conjunction with an article on how the skeleton was made (see publication 6)



During the prolongation of the project – the Spy II Neandertal was finalised. The thorax was reconstructed based on new fossil material for the cervical vertebrae with the rest of the thorax being already constructed from a recent paper in Nature.

> *Gómez-Olivencia A, Barash A, García-Martínez D, Arlegi M, Kramer P, Bastir M, and Been E. 2018. 3D virtual reconstruction of the Kebara 2 Neandertal thorax. Nature communications 9(1):4387.*

Daniel Garcia Martinez (follow up committee) worked on the positioning of the cervical vertebrae onto the thoracic bones of Kebara 2 with A. Barash, E. Been and T. Chapman (RBINS). T Chapman then added parametric surfaces which acted asdifferent connection points through the spine and ribs and a member of RBINS Claude Desmesdt added the cartilage to enable the thorax to be printed. T. Chapman then scaled it to the size of the Spy II skeleton. Due to some pathology in the Kebara 2 spine, Daniel Garcia Martinez, Ella Been and Tara Chapman finalised the position of the new cervical vertebrae. This means that the version which will be available to the public will be the most advanced reconstruction of Kebara 2 that is currently available and also show how the thorax works in a whole skeleton. Once the publication of the skeleton is released then we will release all the bones of Spy II and the reconstructed Spy II skeleton (see publications 6).

Task 4.3 Creation of a digital space network of non-contact moulds – TL: RBINS

RBINS and ADIA will work to create a digital space which will enable the digitised fossils to be easily produced in 3D. This digital space of non-contact moulds will also be accompanied by information on the fossil which will be of pedagogical use. RBINS will upload all the fossils from the digital collection chosen from task 4.2 onto Sketchfab. RBINS and ADIA will also add information markers on the 3D models of the fossils where necessary.

Activities realized and results achieved

This has been finalised although the release of the fossils will be accompanied with an article (see publications 6) detailing how the Spy II reconstruction was performed which is yet to be published.

WP 5 CREATION OF A MULTILINGUAL WEBSITE BASED ON NEANDERTALS – WPL: ADIA

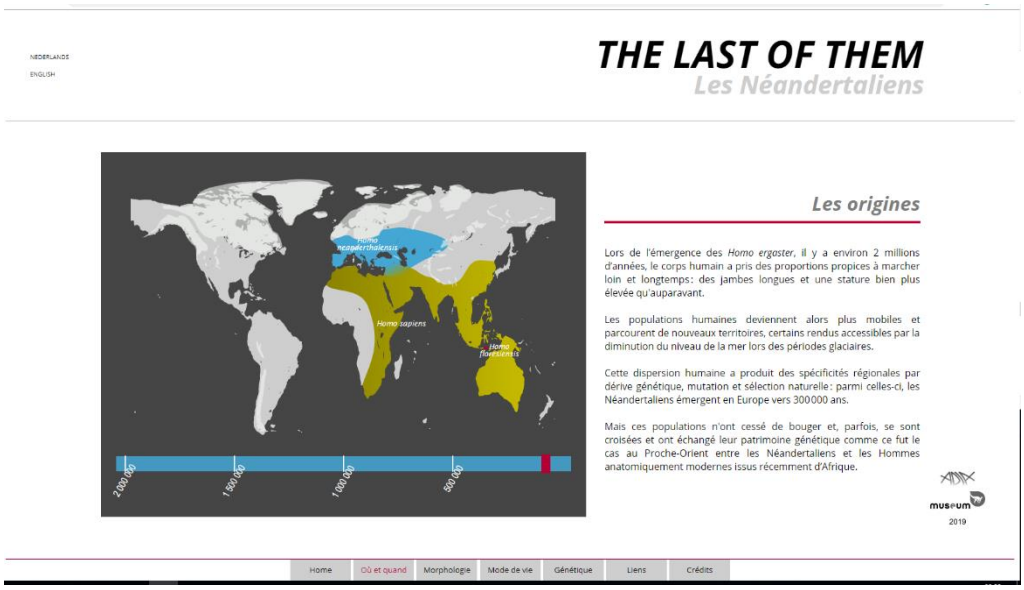
The aim of this WP is to create an International website based on Neandertals. The website will be created by ADIA in conjunction with RBINS and the new state of the art research in Neandertals being performed at VUB and ULB will be incorporated into the website. An experienced half time graphic designer will work with ADIA to create the website and to incorporate 3D models in the website.

Task 5.1 Content of the website – TL: ADIA

ADIA and RBINS will work on the content of the website. This document will then be the basis for the development of the new website. The document will be validated by RBINS scientists (anthropologists, archaeologists, palaeontologists and geologists) and by teachers. The follow up committee will also be invited to evaluate the website.

Activities realized and *results achieved*

The site has now been realised: https://neandertal.naturalsciences.be/. The content of the website was defined and validated for the last report and the follow up committee approved the design of the website. The website is finalised and is in English, French and dutch. The website will also feature a page giving details on where to download the models. However note that the models will only be downloadable once the article on the Spy II reconstruction is published (see publication 6).



Task 5.2 Scenario – TL: ADIA

ADIA will create the scenario and prepare the storyboard. This will include creating a document to detail the structure of the website, menus and submenus and will detail how the different pages will link to each other using a mind mapping approach. This document will then be the basis for the new website. This scenario will be submitted to the follow up committee.

Activities realized and results achieved

It was decided that we would have a classical website containing 25 pages which focus on different aspects of the Neandertals.

http://collections.naturalsciences.be/ssh-projects/projects/neanderthal-3d/project/website/website-scenario-task-5-2/at_download/file. This will be accessed from the first main page (1. Neandertals., what do they tell us) and then there will be submenus; 2. Where and when; 3. General morphology; 4. Lifestyle; 5. DNA; 6. Discussion of the name; 7. Importance of the Belgian fossils in Paleoanthropology (Spy, Engis, La Naulette). There are then additional submenus in 2, 3, and 4 focusing on different aspects. Submenus in 2. Where and When

2.1. The origin of Neandertals (this will be an animated map showing the movements of Neandertals around the world and will also include other fossils); 2.2. Dates;2.3. Climate

Submenus in 3. General morphology

3.1. Comparison of Neandertal and modern human skull; 3.2. Comparison of Neandertal and modern human skeleton; 3.3 Images of Neandertals

Submenus in 4. Lifestyle

4.1. Food; 4.2. Habitat; 4.3. Tools 4.4 Bruniquel reconstructions ; 4.5. Art; 4.6 Funerary practices.

Task 5.3 Text writing and collection of documents – TL: ADIA

ADIA will write the text which will accompany the website and prepare the documents to upload to the website.

Activities realized and results achieved

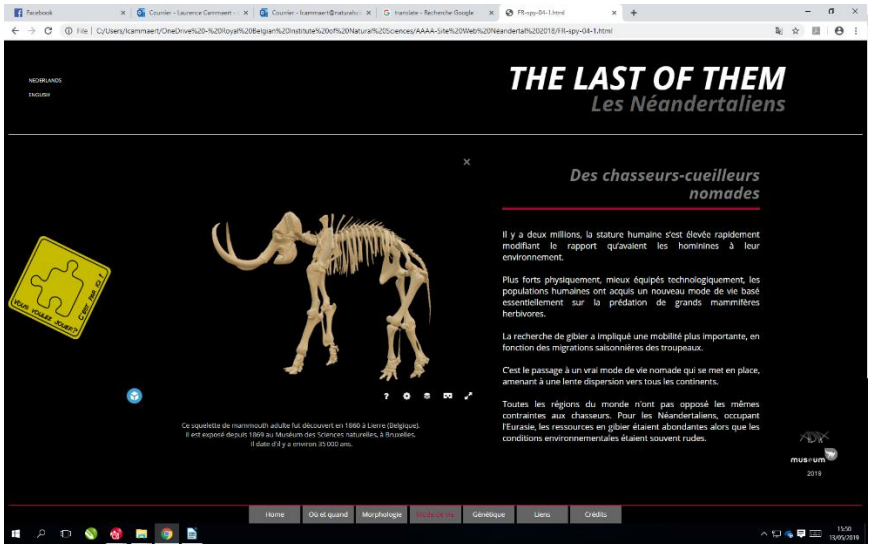
The website has been realised and all text written . https://neandertal.naturalsciences.be/

Task 5.4 Creation and design of the website – TL: ADIA

- ADIA will work on the creation and design of the website. It will follow the graphic chart defined by the graphic designer of RBINS for the Gallery of Human Evolution exhibition hall. ADIA was also involved in the creation of the Gallery of Human Evolution
- The new website will also be linked with the RBINS website.

Activities realized and results achieved

The website is complete. https://neandertal.naturalsciences.be/ The design has been slightly improved and modified to integrate navigation to the fun part of the site. See below a screen shot of the webpage.



Task 5.5 Upload and integration of the 3D models and animation on the Sketchfab platform – TL: RBINS

- Each model will be uploaded onto the Sketchfab platform and checked for quality control
- Each model will also be prepared (quality of the model, background, light, default texture, labels)
- Models will be organised in Sketchfab through a series of folders

<u>Activities realized and results achieved</u>

This task is complete and available models have been uploaded onto Sketchfab. The model, background, light etc have been tested to ensure a quality control of the models (see tasks 4.2 and 4.3 for available models). These models were used in the website.

https://neandertal.naturalsciences.be/en/en-spy-03-2.html

Please note that the page with links to the models will be shown at a later date.

Task 5.6 Testing of the rendering and interactions – TL: ADIA

In this task, the rendering of the 3D models/animations will be evaluated on different devices (screens, tablets, mobile phones).

<u>Activities realized and results achieved</u>

This task is complete and the 3D models and animations work on screens and tablets.

Task 5.7 Translation in Dutch and English – TL: ADIA

The initial website prototype will be in French. ADIA and RBINS will then work with native English and Dutch speakers to produce the text of the website in Dutch and English.

<u>Activities realized and results achieved</u>

This task is complete and the website is In French, Dutch and English.

WP 6 CREATION OF A NEANDERTAL AVATAR BASED GAME - WPL: VUB

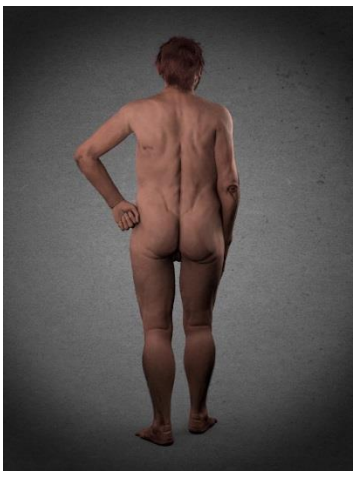
The aim of this WP is to create a Neandertal Avatar based on the Spy II skeleton and to use that avatar in computer games for both educational purposes for school children taking part in the animations by ADIA and for use in serious gaming. The avatar will also be used in the project website.

Task 6.1 Preparation of the reconstructed skeleton - TL: VUB

RBINS will transfer the high resolution models to VUB for pre-processing in order to make the model suitable for use in computer games. This means that the models will be converted into lower resolution models that can be loaded into the Unity 3D Engine. Some models, such as the Neandertal model, are naked and do not have body hair. Hence, the model will be fitted with clothes and hair in order to increase the possibilities for using the models in games for younger children. The VUB will work with RBINS and ADIA to determine the best choice for the appearance such as hair colour, eye colour etc. based on current scientific research.

Activities realized and results achieved

A model is available based on the reconstructed skeleton from RBINS. The model appearance will have ginger hair and blue eyes with a pale skin colour, this is all based on current research in Neandertals. The character being developed by VUB is based on a 2D model which was created by the RBINS museum staff for the Gallery of Human Evolution. The character created for the game is based on this initial character will have Red hair and white skin (possibly with sunburn (similar to RBINS model) but this is not totally relevant – and only if feasibility allows this. This will also ensure that the website has a continuing link with the museum (see below an image of the panel for the RBINS Gallery of Human Evolution). However the character should also be younger looking if possible. There will be several options to the character (naked, clothed in a bearskin cape and possibly with a pair of bearskin pants (knickers). At the end the Neandertal will be clothed in a bearskin cape (with something the hands of bear as the buckle of the cape) and possibly a bearskin hat (looking like the head of a bear).



Task 6.2. Identification of gaming scenarios for specific age groups for educational purposes – TL: ADIA

ADIA will work with all other partners and the member of the follow up committee Vincent Patar, to identify specific scenarios for the developed games. The idea is that the developed game will consist of small challenges or mini-games which will be used in the animations for ADIA. In each of these mini-games, the Neandertal will interact with other species (e.g. mammoths) and for each of those game characters, the game will provide age-adapted additional information specifically targeted at the different age groups. One game will also provide some insight into the activities and daily life of a palaeoanthropologist. Similar to other animations by ADIA, we anticipate scenarios in which the children need to investigate basic scientific issues. For instance, children can use the game to investigate whether Neandertals are taller than us? They can locate the femur, learn to measure it with a digital ruler (as in lhpFusionBox) and compare the lengths of the femur of the Neandertal skeleton and a contemporary skeleton.

Activities realized and results achieved

There are mini games in the website (game definition in Activity Report 2).

Each game is based around a topic discussed on the website. Each win screen (the final screen when the game has ended and the player has won) displays explanations on the topic as well as a link towards the website. The games are inspired from the main type of game present in the world of video games. 8 games were created. They are at different stages of completion. The current title names are temporary. The prototypes of the games are currently produced in French but they will also be produced in Dutch and English at a later date.

Game 1 - Neanderthal in the metro

This is a Point&Click game illustrating Neanderthal morphology. In a metro with many people, the player must identify Neanderthals hidden among modern humans. Neanderthals are also dressed like modern humans. You need to carefully observe the characters morphology to identify them. When you click on one of them, information appears and explains why this character is a Neandertal human. All age groups (children, adult and elderly) and both sexes are present to show the diversity in a population. A prototype has been created although graphic design must be changed and the texts improved.

Neanderthal in the metro-Game Scene

Game 2 Run to eat

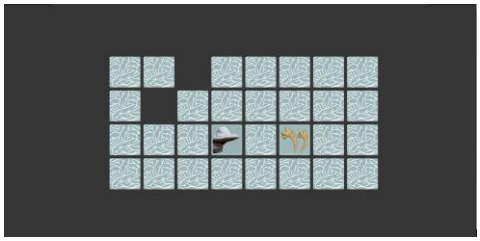
The game is an endless runner platform game with the purpose of showing the type of food Neandertals eat. The player embodies a Neandertal man who must collect food items to feed his family. The character runs without stopping and must jump from platform to platform without falling. On the way, he will encounter two types of food: good food items that he can eat (present at the Paleolithic) and wrong food items that cost a life (not present at the Paleolithic).

If the player has collected at least one copy of each good food item, he wins the game. If the player falls in a hole, he loses the game. If he has collected wrong food items, his lives (represented by family members) decrease. If all of the family members have disappeared, the player loses the game. When he wins or loses the game, explanations are given about each food item to inform the player. The game part is finished. The only missing part is the implementation of the link on the win screen that allows the player to access the website.

Run to eat – Game Scene

Game 3 Memory

This is a classic Memory game where you must find two same images to create a pair. To win the game, you must try to find all of the pairs. In this game, the player discovers raw material used during the Paleolithic. On the win screen, the player can read explanations for each material displayed during the game. The game part is finished. The sources on the use of the different raw materials are being verified. The implementation of the link towards the website on the win screen must still be done.



Memory – Game Scene

Game 4 Taquin

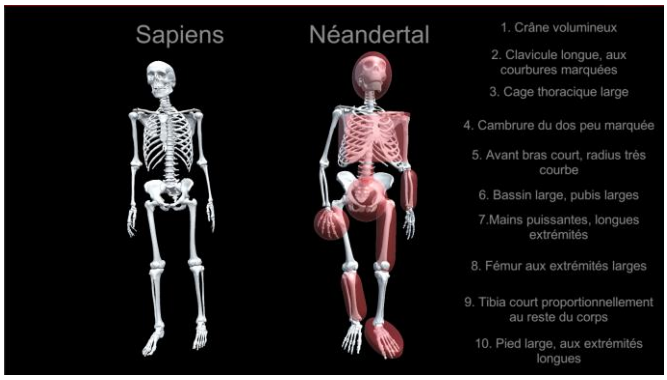
A taquin is a type of puzzle in which the image has been sliced in multiple pieces and then the pieces shuffled. The player must slide the pieces around until he can restore the image. You must to restore the image and for this, you must to slide the pieces. The game has 4 levels which present differents pictures related to the Spy Cave. Each solved image gives explanations about what it shows. The game part is finished. The implementation of the link towards the website on the win screen must still be done.

Taquin – Game Scene

Game 5 10 differences of skeleton

It's a 3D game in wich the player discovers differences between a modern human skeleton and a Neanderthal human skeleton. The Skeletons spin around. The player must click on the Neanderthal skeleton to make the differences appear. If the player finds found all the differences, he wins the game.

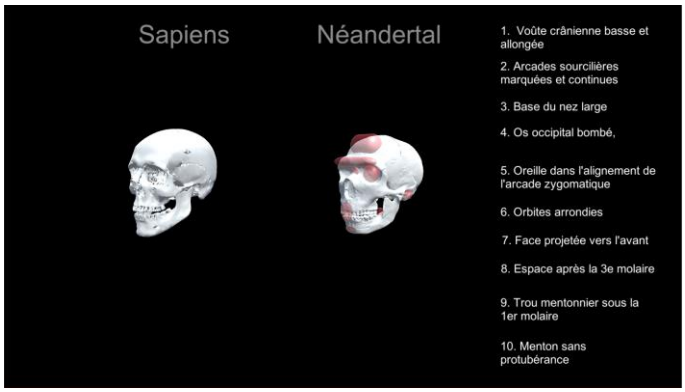
The game part is finished. The implementation of the link towards the website on the win screen must still be done.



10 differences of skeleton – Game Scene

Game 6 10 differences of skull

This is a 3D game in which the player discovers differences between a modern human skull and a Neanderthal human skull. The skulls spin around. The player must click on the Neanderthal skull to make the differences appear. If the player finds found all the differences, he wins the game. The game part is finished. The implementation of the link towards the website on the win screen must still be done.



10 differences of skull – Game Scene

Game 7 Puzzle

This is a classic puzzle game. A picture with four animal skeletons who lived during the Paleolithic has been sliced into pieces. The player must put each piece at the correct place to solve the game. With this game, the player will discover the wildlife of the Paleolithic. If the player solves the puzzle, the win sceen gives an explanation about each animal species encountered in the picture. The game part is finished. The implementation of the link towards the website on the win screen must still be done.

Puzzle- Game Scene

Game 8 Hidden objects

In a modern workshop, the player must find Paleolithic tools (like a scraper, a handaxe,...) which are hidden in the scene.The player must find all of tools before the end of the time to win the game. The win screen and the explainations on it must still be created

Hidden Objects – Game Scene

Task 6.3. Analysis which existing serious games to use for the developed Neandertal avatar – TL: RBINS

The suite of games available at ULB and VUB will be examined for their success and potential suitability to add a Neandertal avatar to by all partners. As an example, the following description is of the "Hit The Rocks" game. This game simply asks the patient to throw a ball in the direction of a pile of blocks. This game is actually practicing balance and trunk control in the patient group as they can change the orientation of the ball by means of trunk movements. This game can be directly translated into a hunting game (for example, by throwing rocks towards mammoths), clearly enriching the game experience of the patients.

Activities realized and results achieved

This task was completed for activity report 2. RBINS worked with both ULB and VUB to analyse which of the games would be used for the serious game. The game chosen as the most ideal was the space ship game. The game to be created is based on an object (Spyrou) moving through corridors and collecting objects. The idea for this game has evolved to be both a serious game played with a Wii or the Kinect system and an educational game for the project website played on the keyboard.

The basic premise of the game has been defined as follows:

At the beginning of the game – a map will flash up and show the correct route. People have to see which way to go and make sure they go the correct way (this is largely for the serious games which also has a cognitive element (known as double tasking as neurological problems also important) (i.e show a map of where to go, the map disappears and then people have to remember the correct way to go). If they go the wrong way – there are several scenarios – the character will die if confronted with a group of angry hyenas or bump into a cave lion. This will end the game. Alternatively they could fall down a hole, startle a flock of bats or get scared by a snowy owl (all have a reduction in torches)

The game will start with Spyrou entering the Spy cave (which has been digitised). Spyrou will then run through the cave and collect lit torches. Spyrou will be naked but as it is in torchlight you will not see any details only the back of Spyrou. There should also be a possibility of him with some pants on so we can decide or choose. The light will dim so he needs to make sure that he collects enough that the light doesn't go out completely (where the game will end). There will be stalagmites and stalagtites in the cave, if Spyrou touches these the torch will also dim (again the torch must not go out completely). Spyrou will need to collect five objects along the way – sticks to make a fire, a handaxe, a scraper and a spear and stones (flint and pyrite). When Spyrou collects one of these objects – it could light up on the screen. At the end Spyrou will arrive in an opening of the cave _ (TBD by BJ). There will be animation of a cave bear. If Spyrou collected the five objects (stones, sticks to make a fire, a handaxe, a scraper and a spear) - the final shot will be Spyrou wearing a bear skin as a cape with a bear head as a hat.

If Spyrou didn't collect the five objects – then he will be eaten by the bear and will have to start again.

After the final animation – there will be a screen with links to the website based on the game. I.e. click on the handaxe and it will take you to the section of the website discussing the tools Neandertals used, the same for the fire, hyenas, bears, spears and scrapers. This gives an educational element to the game. The scraper was used to make the bear skin, the handaxe and spear to kill the bear and the sticks for the fire to cook the bear.

The level of difficulty can be determined by how long you have before the torch runs out.

The game will only run on the latest browser (this will mean the game will be better as more memory can be used). A pop up message will appear informing people that they need the latest browser to run the game. This could be something like 'you are too old'!

Task 6.4 Development of tablet games - TL: VUB

The games will then be developed by VUB using the Unity 3D Game Engine according to the scenarios developed in Task 5.2. The technological platform used for the development of these games enables the distribution of these games on Android, iOS and Windows based mobile platforms via the respective app stores. During the project, the feasibility of this will be investigated.

Activities realized and results achieved

Some of the mini games developed for the website can be developed as tablet games. This will be done once the games for the website are complete (see task 6.5).

Task 6.5 Incorporation of the 3D models into rehabilitation games - TL: VUB

This work package will concentrate on the incorporation of the avatar developed in Task 5.1 into existing serious games defined as the most suitable in task 5.2.

Activities realized and results achieved

A completely new game was defined as a serious game in task 6.3. Although it is still based on ideas from the older space ship game, this game requires a complete game development. Implementation was done in Unity using 3D models available in the Unity asset store and the models made available by RBINS. In the screenshot below the default unity avatar is shown and not the Neaderthal avatar. Navigation of the character through a large cave is available. Whenever he hits any object, he loses one torch as shown on top of the screenshot, making him walk in an even darker environment. Although it seems simple to navigate in such a cave/maze, the fact it gets darker and darker increases the difficulty level significantly, such that quite some practicing seems to be required in order to finish this game.

During the last period of the project, the game was further developed to have the necessary start screens, end screens, embed the links to the different portions of the website for further information etc. More importantly, the logic was realised to have the actual collection of the sticks to make a fire, the handaxe, the scraper and the spear and stones. When these are collected, the final bear is conquered.

Form the game, versions are available as executables for win/linux/mac and local tablet versions for Android and iOS are available. We however did not go through the store validation procedures to have them available from play store and app store. Lastly, the game can be embedded in the museum's website. This way, the same game can be used for the different purposes planned.

Related to rehabilitation games in other projects, VUB's effort shifted gradually to tablet games, controlled with for instance EMG sensors rather than Wii Balance Board and Kinect (as the former is not available at all anymore, while the latter one had several years of discontinuity before becoming available again). The Cave game could be incorporated in the rehabilitation game platform.

In the picture above, the collectible items are shown in the right top and a projected map is shown on the right bottom to help the user to better navigate.

Task 6.6 Game evaluation - TL: ADIA

All developed gaming material needs to be evaluated continuously by the involved stakeholders. ADIA will run an animation based on the new game. Children in the target group will be observed during game play and interviewed by means of structured questionnaires in order to understand whether the provided information in the games is actually correct, whether it is attractive to the children and whether the game mechanics are providing sufficient reward to explore the full game and hence to maximise the potential information transfer.

Activities realized and results achieved

The games were tested with members of RBINS, ADIA and the respective families (including small children and adolescents). The games work fine on tablets but as they are not yet online we were not able to test with the general public. Different age groups were tested and it was found that 12 years old is the best age for the games and information on Neandertals.

4. DISSEMINATION AND VALORISATION

Dissemination and vulgarisation was a task in the project and here we list the tasks and results achieved from WP 7 which was related to dissemination and vulgarisation. The aim of the project was to target different audiences with a view to valorising the digitised fossils. Press releases will be sent out when the publication on the spy II skeleton is accepted. RBINS will work closely with the communication department and will send the press releases to the communication departments of ULB, RBINS and VUB who will then send the press releases to the relevant media.

Activities realized and results achieved

There have been several media appearances featuring the Neandertal skeleton and the biomechanical movement of the skeleton:

- Television documentaries:

- *participation in the documentary 'Qui a tué Neandertal' (screened on France 5, 10/04/2018 and then on Canvas 17/02/19 (with Flemish subtitles).*
- *participation in the documentary "Er was eens" by Diplodokus (screened on Canvas 25/11/2018)*
- *participation in the documentary "Neanderthals: Meet your Ancestors" (screened on BBC2 on 13&20/05/2018)*

-Press interviews:

28/02/2018: interviewed as part of an article for Le Soir Mag "A la découverte des trésors de notre préhistoire."

-Science figured out:

19/02/2019 - Three minute video as part of the 'Science Figured Out' project which aims to bring science closer to citizens https://www.sciencefiguredout.be/did-neandertals-breakdance

Task 7.1 Dissemination to University students and scholars – TL: RBINS

The new tools developed in lhpFusionBox will be of significant interest to palaeoanthropologists as well as anatomists, medical students and students working on comparative morphology studies, measurements, musculoskeletal models and biomechanics. The new tools will be highlighted through a press release detailing the availability of the tools, which will be released with the assistance of the network of the RBINS communication department. RBINS will attend high level conferences such as the European Society of Human Evolution conference in Year 1 and 2 to give feedback on the development of the tools and the availability of the fossils. Results of the outcomes of the project will also be published in peer reviewed international journals.

Activities realized and results achieved

There have been several presentations related to aspects of the project.

Dissemination of general features of project to students and staff at RBINS, ULB and the University of Gent Belgium and also the University of Kent, UK.

These seminars gave a basic introduction to the project and showed the project aims and objectives. The seminar also demonstrated the new developments of tools and offered all LABO students the opportunity to test some of these new tools, in particular the development to do automated measurements.

1. *T. Chapman. 2020. Invited guest for seminar with Tracy Kivell on Scaling and biomechanics in Masters module called 'Skeletal Functional Morphology' at the University of Kent on 07/02/2020.*

2. *Chapman T. 2020. The use of gait analysis and 3D modelling to build evolutionary hypotheses as part of the Biological Anthropology Seminar Series, University of Kent on 06/02/2020.*

3. *Chapman T. 2019. Fossil hominid reconstruction and biomechanical analysis (Homo naledi)- with results from the Neandertal_3D project, Departmental seminar presented at the Laboratory of Anatomy, Biomechanics and Organogenesis, Faculty of Medicine - Université Libre de Bruxelles, Belgium on 18/10/2019.*

4. *Chapman T. 2019. Neandertals on the move (Neandertal 3D), workshop presented 08 May 2019 at RBINS to Biology research students from the masters course at the University of Gent followed by a discussion and practical session on the new tools available in lhpFusionBox (arranged with Dominique Adriens from the follow up committee of Neandertal_3D)*

5. *Chapman T. 2019. Neandertals on the move (Neandertal 3D). Workshop presented 28 February 2019 in RBINS to Archeology masters students from ULB at RBINS.*

6. *Chapman T. 2018. Le project Neanderthal 3D, Departmental seminar presented to staff, masters students and PhD students in medicine at the Laboratory of Anatomy, Biomechanics and Organogenesis, Faculty of Medicine - Université Libre de Bruxelles, Belgium.*

Dissemination of general features of project in National and International seminars

1. *T. Chapman. 2020. Invited guest for seminar with Tracy Kivell on Scaling and biomechanics in Masters module called 'Skeletal Functional Morphology' at the University of Kent.*

2. *Chapman T. 2020. The use of gait analysis and 3D modelling to build evolutionary hypotheses as part of the Biological Anthropology Seminar Series, University of Kent.*

3. *Chapman T. 2020. (Senior keynote speaker) The use of gait analysis and modelling to build evolutionary hypotheses" BoHNes Colloquium, Brussels, Belgium*

4. *Chapman T. 2019. Neandertals on the move (Neandertal 3D). Oral communication presented 06/12/2019 at the Research seminar 'Les singularitiés biologiques de l'humanité deux millions d'années entre biologie et culture at the 'Université Libre de Bruxelles*

5. *Chapman T., Throckmorton, Z., Churchill S., Congdon KA., Marchi D., Zipfel B., Walker C., Hawks J., Van Sint Jan S., Sholukha V., Semal P., Berger L., DeSilva J. 2019. The Gait of Homo naledi. Oral communication presented 19-21 September 2019 at the European Society of Human Evolution, Liege, Belgium*

6. *Chapman T., Tilleux C., Polet C., Hastir J-P., Coche E., and Lemaitre S. 2019. How DSP can reliably determine the sex of ancient populations, with a special test case on Pre-columbian mummies. Poster presented 14 September 2019 at the FASE Symposium, Brussels, Belgium.*

7. Chapman T., Tilleux C., Polet C., Hastir J-P., Coche E., and Lemaitre S. 2019. Can DSP be used on Pre-columbian mummies? Le DSP peut-il être appliquée sur les momies précolombiennes? Oral communication presented 24 January 2019 at the Société d'Anthropologie de Paris (1844èmes Journées de la SAP), Paris.

8. Chapman T. 2019. Neandertals on the move (Neandertal 3D). Oral communication presented 06/12/2019 at the Research seminar 'Les singularitiés biologiques de l'humanité deux millions d'années entre biologie et culture at the 'Université Libre de Bruxelles

9. Chapman T., Van Sint Jan S., Gonidakis P., Jansen B. , A. Balzeau A., Polet C., Cammaert L, Louryan S, Semal P. 2018. "Fossil hominids on the move: new developments in fossil hominid biomechanical analysis", presented at the European Society for the Study of Human Evolution (ESHE), Faro, Portugal. Published in PESHE7 2018:41 (Abstract).

Dissemination of script like operation

1. 22/09/2018: comm. poster: A. Boucherie, C. Polet, Ph. Lefevre, M. Vercauteren, "Two heads are better than one. Investigation on sexual dimorphism of craniometric variables through osteometry and 3D scanning. Question of data acquisition repeatability" One-day Symposium Forensic Anthropology Society of Europe (FASE), Marseille, France.

2. 22/09/2018: comm. oral: A. Boucherie, "Dimorphisme sexuel de la base du crâne : approche ostéométrique et tomodensitométrique" presented at the Research seminar 'Les singularitiés biologiques de l'humanité deux millions d'années entre biologie et culture, CReA-Patrimoine, at the 'Université Libre de Bruxelles.'

3. 24/01/2019: comm. poster: T. Chapman, C. Tilleux, C. Polet, J-P Hastir, E. Coche, S. Lemaitre, "Can DSP be used on Pre-columbian mummies? Le DSP peut-il être appliquée sur les momies précolombiennes?" presented at the Société d'Anthropologie de Paris (1844èmes Journées de la SAP), Paris, 2019.

Dissemination of results of study on non-contact reproduction of cultural heritage objects (from task 4.1 evalution of the virtual reproduction of physical objects)

1. 15/09/2019: comm. oral: S. Louyran, M. Daumas, T. Chapman, N. Vanmuylder, "Nouvel examen des moulages des ossements du squelette néandertalien du Moustier I" presented at the 101e Congres de l'Association des Morphologistes, Rennes, France.

Task 7.2 Dissemination to schools and museums on virtual casting – TL: RBINS

The availability of the fossils will be highlighted on the website and on the RBINS website. When the fossils are available for download on the site, media stations and schools and museums will be contacted to tell them of the project and the fact that rare and important fossils which are important pedagogical materials are available for free download. The education department at RBINS will be able to assist with the provision of a mailing list of both relevant schools and museums and the network of journalists from the communication department at the RBINS will be used. Whilst the target for this is schools and museums, anyone with an interest in human evolution will be able to download the fossils.

Activities realized and results achieved

The release of the fossils will be accompanied with an article (see publications 6) detailing how the Spy II reconstruction was performed. The idea is that the fossils will be released with this publication – this will now hopefully be published in 2022. RBINS has already worked with the press communications

team to prepare them for a press release. A mailing list has already been drawn up for schools with the Education department and the RBINS team work with the president of ICOM so a mailing list will also to ICOM, ICOM Belgium Flanders and Vlaams Museumoverleg. BrusselsMuseums. This way, all schools and relevant museums will be aware that the fossils are freely downloadable.

Task 7.3 Dissemination to electronic visitors – TL: RBINS

The creation of a website on Neandertals will enable more electronic visitors to view the digitised fossils. The more media coverage that is generated from the project, the more electronic visitors will visit the website. It is therefore important that media coverage is not done too early so that the fossils are complete.

Activities realized and results achieved

The release of the website is delayed until the publication of the article on the Spy reconstruction.

Task 7.4 Dissemination to medical patients – TL: ULB

ULB and VUB are specialists in serious gaming. They are currently working on different projects in serious gaming and the avatar will be incorporated into their long standing projects.

Activities realized and results achieved

Dissemination towards clinicians has been performed through publications (see publications in 6).Furthermore, several seminars were organised in order to demonstrate serious gaming in rehabilitation, also including results from this project:

- *Seminar in orthopaedic department of Erasme – 24th of October 2019*
- *Seminar in neuropaediatry department of HUDE – 29th of November 2019.*

Task 7.5 Dissemination via Sketchfab and the creation of a Blog – TL: ADIA

Once the fossils are released, RBINS will work with the head of business development in Sketchfab to provide the maximum amount of exposure to the online community. There is a dedicated museums page with over 350 museums. The RBINS is already a part of this community and the homepage of RBINS will be updated to include much more information and provide a showcase for the digitised fossils. This will be shared via Sketchfab through their website, newsletter and social channels.

5. PUBLICATIONS

The following are publications which are related to the research which are either published (publications 4-12) or which are in submission (1) or preparation (2-3):

1. Chapman, T., Marchi, D., Walker, C., Vereecke, E., Churchill, S.E., Congdon, K.A., DeSilva, J., Zipfel, B., Hawks, J., Van Sint Jan, S., Sholukha, V., Harcourt-Smith, W., Berger, L.R., Throckmorton, Z., **in submissio**n. Gait kinematics of Homo naledi.
2. Chapman, T., Van Sint Jan, S., Mathys, A., Brecko, J., Dewamme, E., Lourayn, S., Cammaert, L., Balzeau, A., E, B., Garcia Martinez, D., Barash, A., Rougier, H., Crevecoeur, I., Jerbi, T., Jansen, B.J., Sholukha, V., Berillon, G., Hambucken, A., Moiseev, F., Polet, C., Beyer, B., Rooze, M., Semal, P., **in preparation**. Part 1: The Spy II Neandertal reconstruction.
3. Chapman, T., Semal, P., Sholukha, V., Bonnechere, B., Louryan, S., Van Sint Jan, S., **in preparation** Part II: Spy Neandertal Walking.
4. Boucherie, A., Chapman, T., García-Martínez, D., Polet, C., Vercauteren, M., Exploring sexual dimorphism of human occipital and temporal bones through geometric morphometrics in an identified Western-European sample. American Journal of Biological Anthropology (Early view : 2022) (Peer reviewed).
5. Daumas, M., Chapman, T., Louryan, S. 2021. The discovery of two new sets of casts, 3D reconstruction and comparison with original fossils. Digital Applications in Archaeology and Cultural Heritage 23, e00204 (Peer reviewed).
6. Chapman T., Tilleux C., Polet C., Hastir J-P., Coche E., and Lemaitre S. 2020. Validating the probabilistic sex diagnosis (DSP) method with a special test case on Pre-Columbian mummies (including the famous Rascar Capac). Journal of Archaeological Science: Reports 30:102250. doi.org/10.1016/j.jasrep.2020.102250 (Peer reviewed).
7. Bonnechère Bruno, S. Van Sint Jan. Rehabilitation. in DHM and posturography, Chapter: 7.2, Publisher: Elsevier. 2019.
8. B. Bonnechère, O. Van Hove, B. Jansen, S. Van Sint Jan. Validation of the Wii Balance Board to assess static balance during dual-task activity in healthy subjects. Medicine in Novel Technology and Devices, 2019, 1, 100003.
9. O. Van Hove, A. Van Muylem, D. Leduc, B. Jansen, V. Feipel, S. Van Sint Jan, B. Bonnechère. Validation of the Wii balance board to assess balance modifications induced by increased respiratory loads in healthy subjects. Gait & Posture, 68:449-452, 2019.
10. B. Bonnechère, B. Jansen, I. Haack, L. Omelina, V. Feipel, S. Van Sint Jan, M. Pandolfo. Automated functional upper limb evaluation of patients with Friedreich ataxia using serious games rehabilitation exercises. J Neuroengineering and rehabilitation, 15:87, 2018, https://doi.org/10.1186/s12984-018-0430-7.
11. B. Bonnechère, V. Sholukha, L. Omelina, S. Van Sint Jan, B. Jansen. 3D Analysis of Upper Limbs Motion during Rehabilitation Exercises Using the KinectTM. Sensor : Development, Laboratory Validation and Clinical Application. Sensors, 22:16, 2018.
12. B. Bonnechère,M. Van Vooren, J-C. Bier, S. De Breucker, O. Van Hove, S. Van Sint Jan, V. Feipel, B. Jansen. The use of mobile games to assess cognitive function of elderly with and without cognitive impairment. Journal of Alzheimer's disease, 64:1285-1293, 2018.

There are 1 papers currently in submission and 2 more in preparation which are linked to the project. Paper 1 is the reconstruction and gait analysis of the fossil hominid *Homo naledi* and is currently in submission. This paper is in part due to result of testing the LhpFusionBox software and making some tools to update the software which enabled fossil hominid reconstructions to be more easily performed. Paper 2 is in preparation and details the Spy II skeleton, both how it was constructed, and the fact that it will be freely available to the general public alongside the fossils which were used to reconstruct the skeleton. This paper argues for a more open community in Paleoanthropology with

institutions sharing their data. Paper 3 details an initial biomechanical analysis of the Spy II skeleton and the potential of the new tools which are being developed. This is based on the development of the muscle wrapping tools. Papers 4-12 are published. Paper 4 looks at the use of digitised objects for scientific study (Task 4.1). Paper 5 is the result of the study on Le Moustier by ULB and RBINS (Task 4.1). Paper 6 is details a study on the Precolombian mummies and the use of an automated script in lhpFusionBox to create a tool to automatically take DSP measurements (Task 3.1). Papers 7-12 are related to WP6 – the creation of serious games.

6. ACKNOWLEDGEMENTS

Researchers are responsible for entering all necessary forms of thanks in a "THANK YOU" section (e.g. if the research was carried out in cooperation with other institutions or in places facilitated by one of the members of the Monitoring Committee).

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