3DMA (3D Model Annotator):
A user-friendly annotation editor for the spatial markup of 3D models

by

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This thesis is dedicated to
God, Mother of God, Michael Archangelos,
my family and all my relatives ...

...who have always supported me
and was there for me in my hardest moments
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Abstract

3DMA (3D Model Annotator): A user-friendly annotation editor for the spatial markup of 3D models.

Annotations are additional information associated with a specific context area in a document or other piece of information. There are a plethora of tools for annotating digital media such as documents, webpages, 2D images, or even messages exchanged in messaging applications. Annotations can augment a piece of text or a part of an image to add a note or a piece of information that can either act as a reminder to the user or to allow the user to communicate the annotated digital media in more detail to another person. While annotating 2D digital media, is something that an abundance of tools performs, 3D annotation is not explored to the same extent. 3D representation of scenes and objects is something that attracts considerable research interest in recent years and has multiple applications in real-life scenarios. While there are a couple of efforts for 3D annotation, the majority of them provide only location-based point annotation or are bound to a specific area of interest, such as health or construction-related applications.

Location-based annotation of Three-Dimensional (3D) digitization stems from the need to provide location-specific information upon 3D content modelling. Some case studies of such 3D content models are, for example, a murder scene, a natural environment, a craft workshop, a tool or a machine, etc. In addition, annotations may relate to the indication of structures; e.g., the pattern of the body of a dead man in a murder scene, a footprint from a boot left in the dirt, motifs on a textile or a vase, the shapes of a handle of a glass carafe, etc. Thereby, there is a need for a system that will facilitate such indications by providing functionalities that increase its automation. Moreover, annotations should be provided with location-specific context and information attached to the 3D model.

To achieve the goal of allowing users to create 3D annotations and 3D extractions patterns in a 3D model, this thesis proposes the 3DMA. 3DMA is a prototyping system that allows users to effortlessly and effectively create 3D annotations with text descriptions and extract 3D patterns from 3D mesh models. 3DMA aims to allow users to load any type of 3D model and annotate either points or areas of the model by providing multiple features that help the users achieve their goal in a 3D model mesh with the similar effort that they would need for a 2D annotation.
Περίληψη

3DMA (Σχολιαστής τρισδιάστατων Μοντέλων): Ένας φιλικός προς το χρήστη επεξεργαστής σχολιασμών για τη χωρική σήμανση τρισδιάστατων μοντέλων.

Οι σχολιασμοί είναι πρόσθετες πληροφορίες που σχετίζονται με μια συγκεκριμένη περιοχή σε ένα έγγραφο ή άλλη πληροφορία. Υπάρχει πληθώρα εργαλείων για σχολιασμό ψηφιακών μέσων όπως έγγραφα, ιστοσελίδες, 2D εικόνες ή ακόμη και μηνύματα που ανταλλάσσονται σε εφαρμογές ανταλλαγής μηνυμάτων. Οι σχολιασμοί μπορούν να επαυξήσουν ένα κομμάτι κειμένου ή μια περιοχή σε έγγραφο ή άλλη πληροφορία που μπορεί είτε να λειτουργήσει ως υπενθύμιση στον χρήστη, είτε να του επιτρέψει να κοινοποιήσει τα σχολιασμένα ψηφιακά μέσα σε άλλο άτομο. Ενώ ο σχολιασμός 2D ψηφιακών μέσων είναι κάτι που εκτελεί μια πληθώρα εργαλείων, ο τρισδιάστατος σχολιασμός δεν έχει διερευνηθεί σε βάθος. Η τρισδιάστατη αναπαράσταση σκηνών και αντικειμένων είναι κάτι που προσελκύει σημαντικό ερευνητικό ενδιαφέρον τα τελευταία χρόνια και έχει πολλαπλές εφαρμογές σε πραγματικά σενάρια. Ενώ υπάρχουν μερικές προσπάθειες για τρισδιάστατο σχολιασμό, η πλειοψηφία τους παρέχει μόνο σχολιασμό σημείων βάσει τοποθεσίας ή περιορίζεται σε μια συγκεκριμένη περιοχή ενδιαφέροντος, όπως εφαρμογές που σχετίζονται με την υγεία ή τον κατασκευαστικό τομέα.

Ο σχολιασμός βάσει τρισδιάστατης (3D) ψηφιοποίησης απορρέει από την ανάγκη παροχής συγκεκριμένων πληροφοριών πιθανώς κατά τη 3D μοντελοποίηση περιεχομένου. Ορισμένες μελέτες εξακολουθούν να έχουν βασίσει το 3D μοντέλο που παράγεται από μια χρήση τρισδιάστατης ψηφιοποίησης σε έναν κανονικό χώρο ή σε μια συγκεκριμένη περιοχή, μεταφράζοντας την εικόνα ή τη σκηνή σε τρισδιάστατη εκμετάλλευση.

Για να επιτευχθεί ο στόχος αυτός, δηλαδή, να επιτρέπεται στους χρήστες να δημιουργούν τρισδιάστατους σχολιασμούς και μοτίβα εξαγωγής, ο σχολιασμός βάσει τρισδιάστατης ψηφιοποίησης επιτρέπει την χρήση εργαλείων τρισδιάστατης ψηφιοποίησης για την δημιουργία τρισδιάστατης σκηνής και μοτίβων που είναι συγκεκριμένα για το 3DMA.
αποτελεσματικά 3D σχολιασμούς με περιγραφές κειμένου και να εξάγουν μοτίβα 3D από 3D μοντέλα πλέγματος. Το 3DMA στοχεύει στο να επιτρέπει στους χρήστες να φορτώνουν οποιονδήποτε τύπο μοντέλου 3D και να σχολιάζουν σημεία ή περιοχές του μοντέλου, παρέχοντας πολλαπλές δυνατότητες που βοηθούν τους χρήστες να επιτύχουν τον στόχο τους σε ένα 3D μοντέλο πλέγματος με παρόμοια προσπάθεια που θα χρειαζόταν για έναν 2D σχολιασμό.
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Chapter 1: Introduction

An annotation can be considered as an extra piece of information that is associated with a particular information carrier. The role of an annotation may be to introduce a comment on the information carrier or add extra meaning to the information carrier. For example, in rural culture marking trees with specific paint colours of symbols could give information regarding their ownership. This stood the same in the case of flocks where each animal was marked for its owner and others to identify. In the same context, annotations became a form of attaching extra information to textual information carriers with the evolution of typography. People are using several modalities to annotate, highlight or give emphasis to text. Text annotations include side notes but also inline annotation such as underlings, highlights, etc. In many cases, the annotation style is something personal to the reader and in some forms encodes information in a way for the specific reader to understand.

The evolution of digital media has provided novel forms of annotating multimodal documents and has extended the notion of annotation to new fields such as photography, digital art, and designs, 3D models, etc. Today several tools exist to assist the annotation of digital media such as documents, webpages, 2D images, or even messages exchanged in messaging applications. In accordance, the definition of annotation has not changed but what has changed is the information that an annotation can hold. Annotations have thus transformed from plain text and marking media to more rich information carriers that can hold a plethora of digital information.

One form of digital annotation remains an immerging trend and challenge. 3D annotations have not been explored to the same extent as other forms of digital annotations. More specifically 3D annotations can be functional for a wide variety of modern yet complex situations such as location-based annotation of Three-Dimensional (3D) digitization in the cases of crime scene investigations, natural environment research, craft workshops, manufacturing environments, etc.

At the same time, other domains of research such as Cultural Heritage Preservation can benefit from multimodal annotations by exploring annotations on digitizations of Cultural Heritage Objects that provide tools for the researchers and curators to better document and thus preserve CH objects and sites. For all the above-mentioned needs there is still today active interest in the provision of a technical solution for the multimodal annotation of the 3D models.

In this research work, the aforementioned technical gap is addressed through the design and implementation of a tool called 3D Model Annotator (3DMA). 3DMA is a prototyping system that allows users to effortlessly and effectively create 3D annotations with text descriptions and extract 3D patterns from 3D mesh models.
3DMA aims to allow users to load any type of 3D model and annotate either points or areas of the model by providing multiple features that help the users achieve their goal in a 3D model mesh with the similar effort that they would need for a 2D annotation.

The remainder of this thesis is divided into the following chapters:

- **Chapter 2**: presents related work in systems that support 3D/2D annotations and 3D/2D model extraction patterns.

- **Chapter 3**: the design process that followed the 3DMA approach.

- **Chapter 4**: presents the 3DMA System, its features as well as the integrated tools.

- **Chapter 5**: describes the evaluation process and the extracted final results.

- **Chapter 6**: presents the conclusion of this thesis and suggestions for future work.
Chapter 2: Related Work

In this section, analysis of relevant to this thesis work is conducted. More specifically topics of interest include technologies to support annotations of 2D and 3D content and pattern extraction from 3D and 2D content.

2.1 3D Annotations

Blend4Web

Blend4Web framework [1] is a 3D scene that can be prepared in Blender and then exported as a pair of JSON and binary files to load in a web application. It can also be exported as a single, self-contained HTML file, in which exported data, the web player GUI and the engine itself are packed. The Blend4Web framework leverages Blender to edit 3D scenes. Content rendering relies on WebGL, Web Audio, WebVR, and other web standards. The image below (Error! Reference source not found.) shows the Solar S system with masterfully done planet models orbiting the sun with interactive captions. Each one of them is attached to a specific planet. If clicked, additional text information will be shown. All this starts with an anchor, which will keep this caption in the depth of the scene. An anchor is a special Blender scene object and its purpose is to set a point that will be used to show text. In the Planetarium app, for example, anchors are attached to the planets and move with them [2]. Comparing the aforementioned system to ours, this system solely targets on point annotations while the 3DMA system is expanded to a plethora style annotation.

![Blend4Web framework demos](image.png)

Figure 1: Blend4Web framework demos [2].
**Sketchfab**

The main product of Sketchfab [3] is a 3D, Virtual reality (VR), and Augmented Reality (AR) model viewer. It enables users to move freely around or inside the 3D scene using the mouse, touch manipulation, VR, or AR. In addition to static 3D models, the viewer can play and control 3D animations. In this framework, 3D annotations (Figure 2 - (a), (b)) are small, clickable notes and stickable in the 3D model. They are useful for adding information to a specific section. Each annotation has a position, a camera position, a title (required), and a description (optional) and they are ordered in a numerical list. The main Sketchfab’s limitation is that it provides only point annotations, in contrast with the 3DMA system which provides more category annotations, complex annotations as well as a variety of editing options for each annotation.

![Sketchfab framework](image)

Figure 2: (a), (b) Sketchfab framework [4].
Autodesk Inventor LT

In the Autodesk Inventor LT framework [5] 3D Annotations are available since 2018. Autodesk Inventor LT supports a lot of different types of 3D annotations (Figure 3 - (a), (b)). Some of them include a) the Dimension annotations. Dimension annotations display and visually identify the exact size, location, and acceptable tolerance values for a selected geometry. b) the Hole/Thread Note annotations that communicate how a hole is to be manufactured. c) Surface Texture annotations that communicate special surface finishes for faces on the model and d) Leader Text and General Note annotations that communicate additional text-based model information.

This system has almost all the functionalities of the 3DMA system, with the very critical difference that the descriptions and the simple point annotations are related with numerical measurement values and not descriptive text. It focuses on the 3D creation and simulation of components and is used for construction purposes and not for commentary.

Figure 3: (a), (b) Screenshots from the Autodesk Inventor LT framework running program from tutorials in YouTube.
Semantic Segmentation

Semantic segmentation [6] is a functional subset or a structural subdivision. It is defined over a given shape and is separated by colour (Figure 4) (e.g. the hand or the head of a human model; the handle of a pot model; the windows of a car model or the wings of a plane model). Similar tools are also the ShapeAnnotator [7] (Figure 5) and the “Semantic Annotation of 3D Surface Meshes based on Feature Characterization” [8] (Figure 6).

Additionally, an “Interactive semantic enrichment tool” for 3D Cultural Heritage (CH) collections were presented in [9] (Figure 7) (Demo example in [10]); it is fully based on the CIDOCCRM schema and supports its sophisticated annotation model. In particular, it adopts a triangle-based representation and offers features for the easy detection of the mesh subset (intersection with elementary primitives, such as spheres or cylinders) to perform more sophisticated selections of the triangulated areas to be annotated. The GUI uses an assisted segmentation approach, usually based on some geometry-based kernels (such as discontinuity of normals, proximity, uniformity of colour, clipping volumes) helping the user in the selection of the area of interest.

Figure 4: Learning 3D mesh segmentation and labeling [6], Semantic segmentation over a human shape [11].
Figure 5: ShapeAnnotator [7], An original mesh has been segmented using Plumber [12] and HFP [13].

Figure 6: Semantic Annotation of 3D Surface Meshes based on Feature Characterization [8], The instances along with their specific relations represent a formal bridge between geometry and semantics.
CHiSEL

Volumetric representations are used to represent complex shapes, not only in medical and biomedical-related fields but also in Cultural Heritage (CH) applications. An example of such a volumetric representation system is the CHiSEL system (Figure 8) (Design of cultural heritage information systems based on information layers [14]). It supports the documentation of artistic and restoration knowledge.

CHiSEL starts from 3D scanned data (triangle meshes) and converts the data into a volumetric representation based on a classic octree structure. Furthermore, it allows the creation of raster information layers (i.e. single numeric values or labels) over the surface of the artwork, created by binding a set of voxels to a common value, which is stored in a relational database. Every single voxel can therefore be associated with several attributes either assigning one or more numerical values or the id of some categories. The selection of a region is performed in the CHiSEL system via the utilization of a painting style approach using a graphics tablet [11].
Figure 8: The result of a painting-driven selection of annotated lines and regions in the CHiSEL system [14] [11].

User-driven characterization

In User-driven characterization [15] [11] each annotated region is selected according to a specific user request or insight (e.g. a small region affected by some degradation process; an area with a bump related to damage that occurred to the shape of the object; etc.) and is linked to some metadata or some information. Below there is an example of the interface of the User-driven characterization (Figure 9) to insert 3D annotations: a new area, A8 (shown in red on the surface of the model (4)), is created in the presented relief. It shows the list of all inserted areas (1), the interaction buttons (3), and the descriptive information about the area (2) [15].

Figure 9: The interface of the User-driven characterization [15].
Invivo Software and other Medical Platforms

In Invivo Software [16] (Error! Reference source not found. – (a), (b)) users can add custom comments and text to any patient scan data in 2D or 3D views only by simple mouse clicking. Useful for landmark identification or anatomy examination purposes, the annotations dynamically adjust with the volume renderings on both the Anatomage Table [17] and Invivo software. Annotations can even be made accordingly as to have filters for sorting into systems and regions when viewing on the Anatomage Table.

Similar frameworks with Invino Software is ITK-SNAP [18] (Figure 11), NVIDIA AI-Assisted Annotation used by MITK [19] [20] (Figure 12), MeVisLab [21] (Figure 13), and 3D Slicer [22] (Figure 14), VANO [23] (Figure 15). These tools contain several ways of 2D and 3D annotations and are for the medical industry usage.

Figure 10: (a), (b) Invivo Software [24].
Figure 11: ITK-SNAP [18].

Figure 12: MiTK [19] [20].

Figure 13: MeVisLab [21].
3D Model Annotation from Multiple Viewpoints for Croquet

In the 3D Model Annotation from Multiple Viewpoints for Croquet [25] (Figure 16) multiple authors can annotate 3D models from multiple viewpoints in a 3D collaborative environment, with a particular reference to the environment provided by Croquet.
The annotations are represented as thumbtacks and are visible through a filter. Additionally, annotations may be represented as a connector, a line connecting two objects, or they may be a marker, displayed as a thumbtack denoting some hidden content that can be made visible when triggered by a user action within a filter. Finally, the design and the preliminary implementation are under discussion.

Figure 16: (a), (b) 3D Model Annotation from Multiple Viewpoints for Croquet [25].
2.2 2D Annotations

VSIm annotation system

The VSIm annotation system [26] (Figure 17 – (a), (b)) provides users with the ability to embed spatially aware commentary, information, para data, and paratext within a 3D environment. The VSIm is an NEH-funded run-time software prototype for interacting with three-dimensional computer models in both formal and informal educational settings. Specifically divorced from the model creation process, the VSIm annotation system urges users to be content creators, project collaborators as well as peer reviewers. Additionally, this system aims to make users independent scholars, editors, and in-service educators, or to give students the ability to embed spatially aware commentary, information, para-data, and para-text within a 3D environment.

Figure 17: (a), (b) VSIm annotation system [26] [27].
Sherlock

Sherlock 7 vision software [28] [29] is an advanced machine vision software interface that can be applied to a wide variety of automated inspection applications. It offers maximum design flexibility and provides a rich suite of proven tools and capabilities that have been deployed in thousands of installations worldwide. The Sherlock processes two-dimensional images by providing the ability for 2D annotation on an image as shown in Figure 18. Additionally, it contains robust tools & communication, camera flexibility, a powerful development interface, and a shape extraction feature.

![Figure 18: Sherlock [28].](image)

Medical Platforms

The Invivo [16] (Error! Reference source not found.), the 3D Slicer [22] (Figure 14), the MeVisLab [21] (Figure 13), and the MITK [19] [20] (Figure 12) are all similar frameworks that provide the ability of 2D annotations in medicine sector. These systems use as input 2D images and videos, produced by x-rays, MRIs, axial examinations, etc., and are the result of users’ examinations. The two-dimensional annotations and remarks are applied to these 2D images and videos data. Due to the context of using these frameworks (medical sector) arises the problem of the category limitation of model and input images. Additionally, the way data is entered and the complexity of these systems, have various limitations to the general public users (e.g. difficulty learning).
2.3 3D Pattern Extraction

3D FeatureXtract

3D FeatureXtract [30] (Figure 19) is an all-in-one complex feature extraction and 3D modelling software system developed with the defined objective of improving the process workflow experience. Its sole purpose is to maximize the efficiency of modelling by providing accurate and easy-to-use precise software tools. Through its tight integration with geo parameters and standards, 3D FeatureXtract allows users to explore, discover, and accurately reference 3D spatial content in their data. Moreover, this system provides the users with a variety of advanced modelling tools, for the easier achievement of their desired results and modifications.

![Figure 19: 3D FeatureXtract [31].](image)

2D-3D Feature extraction and registration of real world scenes

The 2D-3D feature extraction and registration of real-world scenes [32] (Figure 20) present an efficient edge detection algorithm for the extraction of linear features in both range and intensity image data. It simplifies the dense datasets and provides stable features of interest, which are used to recover the positions of the 2D cameras concerning the geometric model for tasks such as texture mapping. The algorithm requires features of interest that are extracted by an analysis of the mean curvature values. This allows the discrimination of different edge types like crease or step edges. The algorithm features computational efficiency, high accuracy in the localization of
the edge points, easy implementation, and robustness against noise. Moreover, the algorithm was initially developed for range image segmentation and has been extended to segment intensity images with some modifications. The generality and robustness of the algorithm are illustrated during the processing of complex cultural heritage scenes. A similar technique was used by the 3DMA system, in one of its Tools, and it’s described in Section 4.4.4 in Method.

Figure 20: [32] (a) Depth image for a 3D model, (b) Binary edge image produced using the paper’s proposed segmentation algorithm, (c) Segmentation results after thinning process projected in the range image, (d) Segmentation results of coloured images using the paper’s proposed algorithm, the red arrows show some selected edges used for registration of 2D-3D data sets.

2.4 2D Pattern Extraction

Sherlock

The Sherlock 7 vision software [28] [29] also includes a Shape Extraction feature (Figure 21). It offers a solution for extracting and inspecting features on parts or assemblies based on their shape. This includes features that are raised, such as embossed characters, or features that are impressed or indented, such as stamped and engraved markings. It also combines multi-directional Software lighting with advanced software algorithms to eliminate surface background effects, such as noise or colour. Finally, it produces an output image focused on the features most relevant to the inspection. This output image can be then inspected using Sherlock vision tools.
Sherlock SE plugins extract surface structure using a process known as ‘shape from shading’. The same process can be used for glare removal from highly reflective parts.

Figure 21: Shape extraction example using Sherlock [29].
Table 1: Comparison matrix between existing systems and 3DMA

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>3DMA</th>
<th>Blend4Web</th>
<th>Sketchfab</th>
<th>Autodesk Inventor LT</th>
<th>Interactive semantic enrichment Tool</th>
<th>CHISEL</th>
<th>User-driven characterization</th>
<th>Inviso Software</th>
<th>Model Annotation from Multiple Viewpoints for Croquet</th>
<th>VSim</th>
<th>FeatureXtract</th>
<th>Sherlock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creation of a new project</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Save progress achieved in a created project</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Open and Edit an existing project</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Load a 3D model to a 3D scene</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Change rotation, orientation and scale of the 3D model</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>2D Point annotations based on a 2D Image</td>
<td>-</td>
<td>-</td>
<td>●</td>
<td>-</td>
<td>-</td>
<td>●</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>3D point annotations based on a 3D model mesh</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>3D group annotations based on a 3D model mesh</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Pen path 3D group annotations based on a 3D model mesh</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>2D pattern extraction from a 3D model</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
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<td>●</td>
<td>●</td>
</tr>
<tr>
<td>3D pattern extraction from a 3D model</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Text description based on a 2D point annotation</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>●</td>
<td>-</td>
<td>-</td>
<td>●</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Text description based on a 3D point annotation</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Text description based on a 3D group annotation</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>User-friendly usage</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Semantic segmentation</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>●</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Information attached in the semantic segmentation</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>●</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Geodesic path per two 3D point annotations, in a 3D group annotation</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>

'●': Yes
'○': Insufficient – Moderate - Partial
'?': No
'?': Unspecified


2.5 Progress beyond the state of the art

Today, digital annotations have increasing interest as well as they are extremely challenging in various domains. More specifically 3D annotations can be functional for a wide range of domains such as location-based annotation of Three-Dimensional (3D) digitization in the cases of crime scene investigations, natural environment research, craft workshops, manufacturing environments, etc. At the same time, other domains of research such as Cultural Heritage Preservation can benefit from multimodal annotations by exploring annotations on Cultural Heritage Objects digitizations so that researchers and curators can document and preserve CH objects and sites. For all the above-mentioned needs there is still active interest in the provision of a technical solution for the multimodal annotation of the 3D models.

By reviewing the related work and state of the art, it appears that, until now, most of the research works have not presented a holistic approach that includes all the functionalities offered by the 3DMA system but they exploit a few annotation styles and techniques (e.g. only Point annotations or Group annotations). The presented system supports in one approach, through five available tools, multiple style annotations (e.g. Point, Group and Pen Group Annotations connected with a three-dimensional straight line and Path Finder Group Annotations connected with a three-dimensional Geodesic line), exploits the technique of 3D pattern extraction as well as it provides users with the functionality of the 3D models' inspection. In each annotation type, both description and editing options are also offered.

Moreover, existing works target a narrow range of users and areas of interest such as technical people (i.e. engineers, architects, civil engineers) and medicals oriented to constructions and health applications respectively. In contrast to this approach, the 3DMA system is addressed to a wider range of users as well as stakeholders (e.g. museums & CH institutions, Content owners & Creative Industries, Researchers, and Academics) and eliminates category restrictions on 3D models.

Furthermore, many of the available systems are not user-friendly but rather complicated and thus it takes a long time for users to properly learn, understand and use them. The aforementioned limitations are covered by the 3DMA system, as it not only provides a user-friendly environment but also offers an ease-of-use for the end-users. Lastly, some of the existing systems are ongoing as they have not been sufficiently completed or have been partially developed.
Chapter 3: System’s Design

3.1 Thesis Objectives

This Master Thesis objectives have been collected through a literature review and the described iterative elicitation process based on multiple collection methods (i.e. brainstorming) regarding the need for the creation of a user-friendly annotation editor for the spatial markup of 3D digitization and environments, on 3D models by providing proper Tools.

The objectives of this thesis are listed below:

- An easy way to create, open and save projects (.3dma files), as well as the loading of the 3D model meshes.

- The creation of Point Annotations, Group Annotations, Pen Group Annotations, and Path Finder Group Annotations with corresponding Group and Point descriptions, as well as editing, adjustments, and modifications abilities at each 3D Point or Group.

- An easy-to-use way to experience the inspection of the 3D model mesh, at each stage of the project development.

- A manageable way to extract 3D patterns and a way for the user to manually mark the 3D extraction area selection. Alongside, the system should include a preview of the 3D extracted pattern, automatic saving of two .png images as well as the options for editing each 3D extracted pattern.

3.2 Design Process

An iterative design process was followed throughout the development lifecycle of the 3DMA system, according to the principles of User-Centered Design (UCD) [33] that were also adopted by the Mingei H2020 EU project, to which this thesis is part. UCD [34] is an iterative design process for interactive applications, systems, and products. Its main characteristic is that it places the end-users and other identified stakeholders’
needs at the centre of each design and development phase of the system (tool, application, or product). The main goal of this process is to ensure that the resulted system meets the user’s needs, supports their goals and objectives, and satisfies the main parameters of usability: ease of use, learnability, effectiveness, efficiency, and satisfaction. There are four main stages in the UCD process (Figure 22):

1. **Understand the context of use**
2. **Specify user requirements**
3. **Design solutions**
4. **Evaluate against requirements**

![Figure 22: The four stages of the UCD process [35].](image)

### 3.2.1 Understand and specify context of use

This stage involved the understanding of the context of the use of the 3DMA system as well as the end-users and other stakeholders, their goals and expectations from using the system, and the environment in which the system will be implemented.

- **Description of context and rationale**
  Annotations are used for many decades as a piece of additional information associated with a specific context area in a document or other piece of information in 2D contexts. People are using several modalities to annotate, highlight or give emphasis to text. Text annotations include side notes but also inline annotations such as underlings, highlights, etc. 3D annotations can be functional for a wide variety of modern yet complex situations such for example location-based annotation of Three-Dimensional (3D) digitization in the cases of crime scene investigations, natural environment research, craft
workshops, manufacturing environments, etc. These requirements regard the need for the creation of a user-friendly annotation editor for the spatial markup of 3D digitization and environments, on 3D models by providing proper tools. To that end, the 3DMA approach addresses not only the need for 3D model annotations but also supports the effortless creation of 3D annotations similar to 2D annotations. In this context, the 3DMA system, a 3D editor was developed.

- **Stakeholders mapping**
  For Stakeholders and End Users, this system refers to the police service for annotating on 3D murder scenes (e.g. investigations, accidents) as well as extracting 3D patterns for various purposes. Specifically, this approach refers to people who design 3D models and want to annotate possible changes that the models may need. Moreover, the system addresses museums & CH institutions and genially people who are involved in cultural heritage and want to export 3D patterns (e.g. embossed designs). Lastly, this system concerns, Conservators, Curators, Museum educators, Content owners & Creative Industries, Researchers and Academics, Craft masters/educators, and Primary educators.

### 3.2.2 Specify requirements

In this stage, the requirements of the 3DMA system were specified to satisfy the users' needs and fulfil its objectives. The main requirements for the 3DMA system are presented below.

**Functional Requirements**

‘Functional requirements define the basic system behaviour. Essentially, they are what the system does or must not do, and can be thought of in terms of how the system responds to inputs. Usually, define if/then behaviours and include calculations, data input, and business processes [36].

This section presents the high-level functional requirements, based on the Section 'Thesis Objectives' (Section 3.1), that 3DMA needs to satisfy. The system’s high-level functional requirements are listed in Table 2:
Table 2: Functional Requirements (FR = Functional Requirements)

<table>
<thead>
<tr>
<th>FR-1</th>
<th>Users should be able to create a new project.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR-2</td>
<td>Users should be able to save progress achieved in a created project.</td>
</tr>
<tr>
<td>FR-3</td>
<td>Users should be able to load a saved project.</td>
</tr>
<tr>
<td>FR-4</td>
<td>Users should be able to load 3D models to a 3D scene.</td>
</tr>
<tr>
<td>FR-5</td>
<td>Users should be able to perform Point-based Annotations on the 3D model.</td>
</tr>
<tr>
<td>FR-6</td>
<td>Users should be able to perform Group Annotations on the 3D model.</td>
</tr>
<tr>
<td>FR-7</td>
<td>Users should be able to perform freestyle Pen Group Annotations.</td>
</tr>
<tr>
<td>FR-8</td>
<td>Users should have full control of the rotation, orientation, and scale of the scene and objects and be provided with usable controls.</td>
</tr>
<tr>
<td>FR-9</td>
<td>Users should be provided with a Tool to extract shapes, structures, and motives from textured 3D models.</td>
</tr>
</tbody>
</table>

Non - Functional Requirements

‘While functional requirements define what the system does or must not do, non-functional requirements specify how the system should do it. Non-functional requirements do not affect the basic functionality of the system (hence the name, non-functional requirements). Even if the non-functional requirements are not met, the system will still perform its basic purpose’ [36]. The system’s Non - functional requirements are listed in Table 3:

Table 3: Non - Functional Requirements (NFR = Non - Functional Requirements)

<table>
<thead>
<tr>
<th>NFR-1</th>
<th>The system should be easy to use.</th>
</tr>
</thead>
<tbody>
<tr>
<td>NFR-2</td>
<td>The system should provide means to help a user to learn how to use the platform.</td>
</tr>
<tr>
<td>NFR-3</td>
<td>The system should be able to run easily as an executable on Windows PCs.</td>
</tr>
</tbody>
</table>
3.2.3 Design Solutions

This stage focuses on the design of the User Interface (UI) prototypes for the 3DMA system. In the beginning, low fidelity prototypes were created to visualize the core features of the 3DMA system. During the iteration phases, experienced interaction designers evaluated the low-fidelity prototypes and thus the final design of the high-fidelity prototypes of the system was conducted.

3.2.4 Evaluate Against Requirements

Evaluation is an integral part of the UCD methodology and the embedded iterative design approach and it is suggested to take place from the very early stages of the design cycle. Its main aim is to help the design and development team uncover and fix potential usability and user interaction problems introduced in the prototype design at a stage where changes are less costly. During the development of 3DMA Tools and features, multiple expert-based evaluations in the form of cognitive walkthroughs were conducted by HCI usability experts, aiming to eliminate serious usability problems before proceeding to user testing.

After the finalization of the hi-fidelity mockups, in Step 3 “Design Solutions”, were conducted retroactively two steps: First, a Cognitive walkthrough evaluation was held over the hi-fidelity mockups (Evaluate Against Requirements), on which were conducted new additions in the functional requirements, for the features and the Tools of the system (Specify User Requirements). Lastly, in the second step, new high-fidelity were designed interactive prototypes, about the new functional requirements (Design Solution) of the previous step. The retrospective was finished when the system Tools and features requirements were finalized.

Below there is an indicative high-fidelity prototype of the 3DMA system in the early stages of its design, before the first Cognitive walkthrough evaluation (Figure 23 (a)), and an indicative high-fidelity prototype of the 3DMA system, after the first Cognitive walkthrough evaluation (Figure 23 (b)).
Figure 23: (a) Indicative high-fidelity prototype of the 3DMA system, in the early stages of its design, before the first Cognitive walkthrough evaluation, (b) Indicative high-fidelity prototype of the 3DMA system, after the first Cognitive walkthrough evaluation.
Chapter 4: 3DMA System

Due to the need for 3D model annotations and the effortless creation of 3D annotations similar to 2D annotations, the 3D Model Annotator (3DMA) system, a 3D annotation editor was developed. The main goal of this system is the design and developing a user-friendly annotation editor for the spatial markup of 3D models.

The 3DMA introduces a holistic approach to the process of creating and editing 3D Point or Group annotations, represented as coloured 3D spheres, on a 3D model mesh. The presented system supports in one approach, through five available tools, multiple style annotations (e.g. Point, Group and Pen Group Annotations connected with a three-dimensional straight line and Path Finder Group Annotations connected with a three-dimensional Geodesic line), exploits the technique of 3D pattern extraction as well as it provides users with the functionality of the 3D models' inspection. In each annotation type, both description and editing options are also offered. Additionally, it includes the possibility of creating a project, its storage as well as its opening for further processing through a variety of features. Lastly, the 3DMA system is addressed to a wider range of users as well as stakeholders (e.g. museums & CH institutions, Content owners & Creative Industries, Researchers, and Academics) and eliminates category restrictions on 3D models.

4.1 Notation

We very often omit the term virtual when talking about virtual cameras, virtual viewpoints, virtual positions, in a virtual 3D environment.

<table>
<thead>
<tr>
<th>3D Model Mesh</th>
<th>A 3D triangle-based model mesh.</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mathbf{p} = [x, y, z]^\top )</td>
<td>A point in 3D space.</td>
</tr>
<tr>
<td>( \mathbf{ep} = [x, y]^\top )</td>
<td>A point in a 2D image space, and indicates a detected edge.</td>
</tr>
<tr>
<td>( \mathbf{p}_i = [x_i, y_i, z_i]^\top )</td>
<td>A set of ( n_i &gt; 1 ) points.</td>
</tr>
<tr>
<td>( \mathbf{c} = [x, y]^\top )</td>
<td>A user point click in the (2D) screen space.</td>
</tr>
<tr>
<td>( \mathbf{c}_i = [x_i, y_i, z_i]^\top )</td>
<td>A set of ( n_i &gt; 1 ) point clicks.</td>
</tr>
<tr>
<td>Group</td>
<td>A connected and ordered set of 3D points ( \mathbf{p}_i, n &gt; 1 ) points.</td>
</tr>
<tr>
<td>Triangle ( T )</td>
<td>A triangle ( T ) in 3D space is comprised of 3 3D points.</td>
</tr>
</tbody>
</table>
A 3D mesh of triangles is comprised of a set of 3D points \( p_i \) and a set of triangles \( T_i \). Triangles are represented as a set of triplet indexes, on the set of points. Triangle \( T_i \) is comprised of points \( p_0, p_1, \) and \( p_2 \) and is represented by indices \([i_0, i_1, i_2]\).

<table>
<thead>
<tr>
<th>( T_i )</th>
<th>A 3D mesh of triangles is comprised of a set of 3D points ( p_i ) and a set of triangles ( T_i ). Triangles are represented as a set of triplet indexes, on the set of points. Triangle ( T_i ) is comprised of points ( p_0, p_1, ) and ( p_2 ) and is represented by indices ([i_0, i_1, i_2]).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>3D Vector</strong></td>
<td>A 3D Relocation is a 3D vector.</td>
</tr>
<tr>
<td><strong>Virtual world Origin</strong></td>
<td>The origin of our virtual world is point ( O = [0, 0, 0] )^T. The 3 axes of this world are denoted as ( xx', yy', zz' ) axes and their unit vector as ( u_x, u_y, u_z ), respectively.</td>
</tr>
</tbody>
</table>

A virtual camera is located at its centre \( t \) (a 3D point) and oriented as a rotation \( R \) (3 by 3 rotation matrix). The camera’s principal axes are then oriented as \( R*u_z \) and the other two as \( R*u_x \) and \( R*u_y \). The pose of this camera is denoted as \([R \ t]\), which is a 3 by 4 matrix.

### 4.2 3DMA Implementation Environment

The system requires a platform that covers many different aspects of the system development process such as rendering, physics, animation, and the creation of the user interface. Also, it would be useful to find a platform that will be accompanied by documentation, developer community, low cost, and multiplatform distribution. All of the abovementioned can be found in Unity Engine using scripting in C# [37] (Figure 24).

![Figure 24: A screenshot of the 3DMA interface being developed in Unity.](image-url)
4.3 3DMA Key Features

4.3.1 System Panel

Description

A panel is provided at the top of the system, divided into two sections, the left, and the right. Both domains consist of UI buttons. The system provides an appropriate text indication for each button for better understanding (Tooltip feature).

![System panel](image)

Figure 25: System panel.

Left Buttons

- **Create New Project**: It allows a user to create a new project simply by selecting a 3D model (.obj file) and a unique name (per folder) for the project (Section 4.3.3).

- **Open Project**: It gives the user the opportunity, at any time, to choose to open one of his existing projects (.3dma file) (Section 4.3.6).

- **Save Changes**: Saves all changes that have been made and have not been saved so far, by any Tool of the system (Section 4.3.4).

- **Reset to Initial State**: Discard all changes that have been made, by any Tool of the system, and have not been saved (Section 4.3.5).

![Left-oriented buttons](image)

Figure 26: Left-oriented buttons in the system panel.

Right Buttons

- **Inspection**: Inspection Tool (Section 4.4.1).
4.3.2 Instructions

The system provides instructions of use for each of the five Tools.

**Inspection Tool Instructions**

**FreeLook Camera:**

- keyboard keys:
  - 'Q': Moves camera Up
  - 'E': Moves camera Down
  - 'W': Moves camera In
  - 'S': Moves camera Out
  - 'A': Moves camera Left
  - 'D': Moves camera Right
  - 'Shift': Speed above actions

- Mouse:
  - Pressed Left-click & Relocate:
    Rotates the Camera to the directional axis.

**Trackball Camera:**
- Mouse:
  - Pressed Left-click & Relocate:
    Rotates the Camera to the directional axis in circular orbit.
  - Pressed Middle-clicks & Relocate:
    Relocates the Camera to the directional axis.
  - Middle-scrolls: Zoom Camera In & Out.

Figure 28: Inspection Tool Instructions.

**Simple Annotation Tool Instructions**

**Annotation Methods:**
- Point Annotation
- Group Annotation
- Pen Group Annotation

**Ways for Annotating:**
- Mouse Left-click presses on the 3D model mesh.
- Mouse location in combination with the 'A' pressed keyboard key on the 3D model mesh.
Each 3D red sphere has Point Editing Options. These options are represented in the form of buttons in a circular Menu.

How to open the Point Editing Options Menu:
- Press mouse Right-click on a red 3D sphere.

Keyboard keys shortcuts:
- 'Left Alt': Enables the Inspection Mode and disables the Point Selection Mode. To return in the Point Selection Mode key 'Left Alt' must be pressed once more.

Figure 29: Simple Annotation Tool Instructions.

Path Finder Annotation Tool Instructions

Annotation Methods:
- Group Annotation

Ways for Annotating:
- Mouse Left-click presses on the 3D model mesh.

Each 3D purple sphere has Point Editing Options. These options are represented in the form of buttons in a circular Menu.
How to open the Point Editing Options Menu:

• Press mouse Right-click on a purple 3D sphere.

Keyboard keys shortcuts:

• 'Left Alt':

  Enables the Inspection Mode and disables the Point Selection Mode. To return in the Point Selection Mode key 'Left Alt' must be pressed once more.

---

Figure 30: Path Finder Annotation Tool Instructions.

3D Pattern Extraction Annotation Tool Instructions

Annotation Methods:

• Point Annotation

• Pen Group Annotation

Ways for Annotating:

• Mouse Left-click presses on the 3D model mesh.

• Mouse location in combination with the 'A' pressed keyboard key on the 3D model mesh.

Each 3D green sphere has Point Editing Options. These options are represented in the form of buttons in a circular Menu.
How to open the Point Editing Options Menu:

- Press mouse Right-click on a green 3D sphere.

Keyboard keys shortcuts:

- 'Left Alt':
  
  Enables the Inspection Mode and disables the Point Selection Mode. To return in the Point Selection Mode key 'Left Alt' must be pressed once more.

---

![Figure 31: 3D Pattern Extraction Annotation Tool Instructions.](image)

**Mark Area to Extract 3D Patterns Tool Instructions**

The parallelogram has Parallelogram Editing Options. These options are represented in the form of buttons in a circular Menu.

How to open the parallelogram Editing Options Menu:

- Press mouse Right-click on Screen space.

Initial Parallelogram's Placement:

- Through Parallelogram Editing Options Menu.
- Press Mouse Left-click on a 3D point on the 3D model.

Parallelogram Relocation Mode:
• keyboard keys:
  - 'Q', 'E': Relocation in x-axis
  - 'W', 'S': Relocation in z-axis
  - 'A', 'D': Relocation in y-axis
  - 'Shift': Speed above actions

• Can be enabled by:
  - Keyboard key 'B'
  - Parallelogram Editing Options Menu

Parallelagram Rotation Mode:

• keyboard keys:
  - 'Q', 'E': Rotation in x-axis
  - 'W', 'S': Rotation in z-axis
  - 'A', 'D': Rotation in y-axis
  - 'Shift': Speed above actions

• Can be enabled by:
  - Keyboard key 'N'
  - Parallelogram Editing Options Menu

Parallelagram Resize Mode:

• keyboard keys:
  - 'Q', 'E': Resize in x-axis
  - 'W', 'S': Resize in z-axis
  - 'A', 'D': Resize in y-axis
  - 'Shift': Speed above actions

• Can be enabled by:
  - Keyboard key 'M'
  - Parallelogram Editing Options Menu

Parallelagram Plane Rotation Mode:
### keyboard keys:
- 'W', 'S': Plane Relocation in z-axis
- 'Shift': Speed above actions

### Can be enabled by:
- Parallelogram Editing Options Menu

### Disable Above Enabled Modes:
- keyboard key 'L'
- Parallelogram Editing Options Menu

### 3D Pattern Extraction Steps:
1) Place the parallelepiped in the desired area. The green side defines the 3D area that the 3D Pattern Extraction Algorithm will use to calculate the final edge points. It is also important to mention that the algorithm does not take into account the 3D model mesh that exists underneath the green plane.

2) Change accordingly the values in the settings in the '3D Pattern Extraction Algorithm' area, guided from the preview at the bottom right orientation image.

3) Find and press the '3D Pattern Extraction' button in the Parallelogram Editing Options Menu.

### '3D Pattern Extraction Algorithm' Variables
- **Bottom Threshold:**
  The bottom Threshold is connected with the Upper Threshold and it is analyzed below.

- **Upper Threshold:**
  Weak (Bottom) and Strong (Upper) Threshold refers to the last stage of the 3D Pattern Extraction Algorithm, named 'Hysteresis',
which has two stages. In the first stage, it discards all the values that are less than the Weak Threshold and keeps the values that are greater than the Strong Threshold. The intermediate values are reserved for the second stage and are called 'Weak Edgels'. 'Edge' is the final stage and the 'Edgel' is the term of the edge before the final stage, the intermediate results of 'Hysteresis'. In the second stage, it is checked which of the 'Weak Edgels' are directly related to some 'Strong Edge'. Those that are connected are upgraded to 'Strong Edge' and the rest will be discarded. The algorithm that is used runs all the upgrades again until it exhausts all the cases where a 'Weak Edgel' is connected to a 'Strong Edge' or to an upgraded 'Strong Edge'. In addition, it is worth noting that Weak Threshold does not make sense to be greater than Strong Threshold, so if this happens, from user's mistake, the system swaps their values.

- **Kernel Diameter:**
  Defines the diameter of the neighbourhood (Kernel) whose samples are used for the Gaussian Smoothing (blurring). The diameter is only odd numbers >3 (3x3, 5x5, 7x7, etc.).

- **Blurring Effect:**
  The Blurring Effect is the Standard Deviation, which determines how strong is the blurring effect. In practice, the Standard Deviation in the Gaussian Smoothing filter is to what extent the filter reduces the deviation of the pixel values in the image between input and output. It was stated if there is more or less effect from the input.

- **Detect Edges by:**
  It is a dropdown button that gives users the ability to choose how
the system will detect the edges in the 'Mark Area to Extract 3D Patterns'. The system provides two options for detection, the Depth, and the RGB_Intensity. Depth uses the depth texture image from the camera to the 3D model mesh while the RGB_Intensity uses the colour differences image of the 3D model mesh, accordingly always to the 3D parallelepiped and its inner green plane.

- Resolution X:
  Defines the orthographic camera resolution on the x-axis.

- Resolution Y:
  Defines the orthographic camera resolution on the y-axis.

Keyboard keys shortcuts:
- 'Left Alt' :
  Enables the Inspection Mode and disables the Point Selection Mode. To return in the Point Selection Mode key 'Left Alt' must be pressed once more.

Figure 32: Mark Area to Extract 3D Patterns Tool Instructions.
4.3.3 Create Project

Description

The system provides the users with the ability to create a new project to add, save or edit annotations, using the Tools of the 3DMA system, and afterwards to track, share and/or optimize the status of their previous actions on the 3D model mesh.

Visualization

Under this pipeline, the creation of a new project is a very easy process. In the left-oriented panel of the system, there is a button for creating a new project. It can be pressed at any time, regardless of whether a project has been opened or not. If there are no new changes in an opened project or the 3DMA system is just initiated, a window for creating a new project will open directly. Otherwise, the system will pop up a question window, asking the user if he/she wants to save the new changes in the current 3D model mesh. After the user's choice (Save/ Don't Save), the window for creating a new project will open. This window requires two fields to be filled. The first is an input field text type, which requires the name that the user wants to name the project. The other field is the selection of a '.obj' file, which will be the 3D model mesh that the user wants to annotate.

The project will be saved in the same folder with the '.obj' file, to work properly. When both fields are filled, the system examines if the given project name is already existing in the folder of the '.obj' file. If this is the case, the user will have to choose a different unique name; for the system to give the ability to create a new project. If that does not exist, then the 'Create' button will be activated. If the user presses it, the system will load and open the selected 3D model mesh. To save the new project creation, the 'Save Changes' button must be pressed, which is near to the project creation button, on the left-oriented side of the panel.

Use Case

A user is being informed about the existence of the 3D model annotator system and wishes to use it. He/she then decides to open the 3DMA application and create a new project. The 3D model mesh user will then use the 'krini_mpempo.obj' from the cultural inheritance domain.
Create a new Project

The stages of creating the new project are:

**Step 1:** The user will find and press the 'Create New Project' button, which exists on the left-oriented side of the system panel.

![Figure 33: Step 1 of the 'Create a new Project'.](image1)

**Step 2:** After completing step 1, a pop-up window displayed to the screen requests from the user to fill in two fields.

![Figure 34: Step 2 of the 'Create a new Project'.](image2)
**Step 3:** The first is a text input field, which is the project name, that the user prefers to give to the new project. The user will name this project 'Krhnh'.

![Figure 35: Step 3 of the 'Create a new Project'.](image)

**Step 4:** The second field is a redirect button, for the user to choose the folder path of the .obj file, which is the desired 3D model mesh. User selects the 3D model mesh 'krini_mpempo.obj'.

![Figure 36: Step 4 of the 'Create a new Project'.](image)
**Step 5:** Since the user has never created another project again, the given name is unique, and therefore the 'Create' button will be activated. In case that the current project has the same name as another one, a warning message would be displayed for the user to change the project name, and the 'Create' button would be disabled.

![Figure 37: Step 5 of the 'Create a new Project'.](image1)

**Step 6:** After the user presses the 'Create' button, a loading bar is displayed on the screen, on the bottom oriented of the system indicating that the 3D model mesh is loading.

![Figure 38: Step 6 of the 'Create a new Project'.](image2)
Step 7: When the loading bar is fully loaded the 3D model mesh is displayed on the screen.

Figure 39: Step 7 of the 'Create a new Project'.

4.3.4 Save Changes Option

Description

The system gives the option to save the changes that have been made by the user, for each project. This option is provided to maintain the desired status of annotations in a 3D model mesh.

Visualization

The 'Save Changes' option is given when a project has been fully loaded and there has been at least one change on the 3D model mesh. Alternatively, 'Save Changes' appears when a new project is being created and the 3D model mesh is fully loaded. If no changes have been made, the project 'Save Changes' option is disabled. When the 'Save Changes' button is active and it is pressed, this button will be deactivated and the system will save the current status of the project with the new changes in a '.3dma' file, with the proper information. If this file has already existed, it is renewed properly, otherwise it is created.
Use Case

As the next step of the previous Use Case in Section 4.3.3, the user wishes to save the created project. After the successful saving of the project, the user makes two new Group Annotations via the Simple Annotation Tool (Section 4.4.2) and saves them too.

Saved progress achieved in a created project

The stages of saving the newly created project and the two new Group Annotations are:

**Step 1:** The user locates the button for the saving changes, in the left-oriented panel of the system. Notices that the button is active and presses it.

Figure 40: Step 1 of the 'Saved progress achieved in a created project'.
**Step 2:** The button will be disabled, indicating that the created project has been saved successfully.

![Figure 41: Step 2 of the 'Saved progress achieved in a created project'.](image1)

**Step 3:** The user zooms in the Trackball camera and creates two new Group Annotations using the Simple Annotation Tool (Section 4.4.2).

![Figure 42: Step 3 of the 'Saved progress achieved in a created project'.](image2)
Step 4: The 'Save Changes' option will be activated and the user presses it once again. The button will be disabled indicating that the two new Group Annotations have been saved successfully.

Figure 43: Step 4 of the 'Saved progress achieved in a created project'.

4.3.5 Reset to Initial State Option

Description

Along with the option to save project changes, there is also the option to reset the project changes back to the initial state. This option is given to the user to be able to undo the last changes in case that he/she wishes to discard them.

Visualization

This option is given when a project has been loaded and there has been at least one change on the 3D model mesh, just like the 'Save Changes' option. If no changes have been made, the project’s 'Reset to Initial State' option is disabled. When the reset button is active and pressed, the system reloads the initially '.3dma' project file contents to the 3D model mesh, thus rejecting the new ones. Since those changes were not saved, the '.3dma' file contains the contents before the changes.
Use Case

As the next step of the previous Use Case in Section 4.3.4, the user creates some new annotations using the Simple Annotation Tool (Section 4.4.2). The user creates three different Group Annotations, with a Group description for each one. After creating them, the user realizes that he/she made a mistake in the annotations area and he/she wants to delete them all. There are two ways to do this, either to delete the Group annotations one by one, from the Point Editing Options (in Section 4.4.2) provided by the system or to press the 'Reset to Initial State' button, from the left-oriented top side of the panel system. The user chooses the second choice.

Reset progress achieved in a created project

The stages for discarding the three new Group Annotations are:

**Step 1:** The user locates the reset changes button in the left-oriented panel of the system.
**Step 2:** The user notices that the button is active and presses it. A confirmation window for resetting the new changes to the initial state pops up on the screen, and the user presses the 'Reset' button.

![Figure 45: Step 2 of the 'Reset progress achieved in a created project'.](image1)

**Step 3:** The 'Reset to Initial State' button will be disabled and the new changes will be discarded successfully.

![Figure 46: Step 3 of the 'Reset progress achieved in a created project'.](image2)
4.3.6 Open Project

Description

The system allows users to open an existing project to inspect, edit and change the status of their previous actions on a 3D model mesh.

Visualization

A new project can be opened at any time in the system. Next to the 'Create New Project' button there is the 'Open Project' button and it is always enabled. If it is pressed, the system will check if there is any opened project in the 3DMA and if there are any unsaved changes in it. If there are new changes in an opened project, the system will pop up a question window and ask the user if he/she wants to save the latest changes. After the user's choice (Save or Don’t Save and not the 'Cancel' option), a window will open to select a '.3dma' file (another project). If there are no new changes in an opened project, or the system is just initiated, the window for selecting a 3D model mesh will open directly. Once a '.3dma' file is selected, the system loads it for editing. If the '.3dma' selected file (project) is corrupted, the system will pop-up an appropriate message 'Unable to load file' (Figure 47).

![Figure 47: Pop-up information window 'Unable to load file'.](image)

Use Case

As the next step of the previous Use Case in Section 4.3.5, the user creates one new Group Annotation using the Simple Annotation Tool (Section 4.4.2). The user decides that he/she doesn't want to save the new Group Annotation but to open a different existing project, which also belongs to the same category as the present (Cultural Inheritance).
Load an existing 3D model mesh to a 3D scene

The stages of loading an existing 3D model mesh are:

**Step 1:** The user locates and presses the 'Open Project' button.

![Figure 48: Step 1 of the 'Load an existing 3D model mesh to a 3D scene'.](image1)

**Step 2:** There are unsaved changes in the current project, so a window will open asking the user if he/she wants to save the unsaved changes. Since the user decides to discard the latest changes in the current project he/she presses the 'Don't Save' button.

![Figure 49: Step 2 of the 'Load an existing 3D model mesh to a 3D scene'.](image2)
**Step 3:** The current project will close and another window will open, asking the user to select a '.3dma' file project.

![Figure 50: Step 3 of the 'Load an existing 3D model mesh to a 3D scene'.](image)

**Step 4:** The user selects a '.3dma' file project and a bar starts to load, indicating that the 3D model is loading.

![Figure 51: Step 4 of the 'Load an existing 3D model mesh to a 3D scene'.](image)
**Step 5:** The selected project opens after the loading bar is fully loaded.

![Figure 52: Step 5 of the 'Load an existing 3D model mesh to a 3D scene'.](image)

### 4.3.7 Settings Options

The system provides some section fields which the user can change accordingly, for the easier use of the system. These section fields mainly consist of input fields and have by default initial values. If any of these fields in any section are changed, the system allows the re-initialization of these values, via a button. Each section field in Settings Options is visible or not, depending on the selected Tool and which camera is enabled. Moreover, the system provides a button Menu regarding the set of the annotations of all annotation Tools (three (3) such Tools). This Menu is placed at the bottom of the Settings Options area and it is always visible. The Settings Options are visible and available at any time by the user in each Tool. There is, however, the possibility of hiding (and reshowing again) the Settings Options, for the maximum utilization of the application environment area.

The section fields provided by the system in Settings Options are as follows:

**A. General Settings (Figure 53) (Always available)**

- **Line Thickness.** The degree of thickness of the three-dimensional line connecting the 3D points into the Group Annotations (in the Simple Annotations Tool, in Section 4.4.2 and Path Finder Annotation Tool, in Section 4.4.3) and Pen Group Annotations (in the Simple Annotations Tool in Section 4.4.2), from primitive to primitive.
❖ **Frame 3D Model.** Positions the active camera in a position where the 3D model mesh is visible and framed in the system’s screen space, through a button. If the enabled camera is the Trackball, this option resets the Camera’s anchor to the center of the 3D Model mesh.

B. **3D Pattern Extraction Algorithm (Figure 54)** (Available if the user is in the 'Mark Area to Extract 3D Patterns' Tool in Section 4.4.4)

❖ **Bottom Threshold.** The bottom Threshold is connected with the Upper Threshold and it is analyzed below.

❖ **Upper Threshold.** Weak (Bottom) and Strong (Upper) Threshold refers to the last stage of the 3D Pattern Extraction Algorithm (in Section 4.4.4, in Method), named 'Hysteresis', which has two stages. In the first stage, it discards all the values that are less than the Weak Threshold and keeps the values that are greater than the Strong Threshold. The intermediate values are reserved for the second stage and are called 'Weak Edgels'. 'Edge' is the final stage and the 'Edgel' is the term of the edge before the final stage, the intermediate results of 'Hysteresis'. In the second stage, it is checked which of the 'Weak Edgels' are directly related to some 'Strong Edge'. Those that are connected are upgraded to 'Strong Edge' and the rest will be discarded. The algorithm that is used runs all the upgrades again until it exhausts all the cases where a 'Weak Edge' is connected to a 'Strong Edge' or an upgraded 'Strong Edge'. In addition, it is worth noting that Weak Threshold does not make sense to be greater than Strong Threshold, so if this happens, from user’s mistake, the system swaps their values.

❖ **Kernel Diameter.** Defines the diameter of the neighborhood (Kernel) whose samples are used for the Gaussian Smoothing(blurring). The diameter is only odd numbers >3 (3x3, 5x5, 7x7, etc.).

❖ **Blurring Effect.** The Blurring Effect is the Standard Deviation, which determines how strong is the blurring effect. In practice, the Standard Deviation in the Gaussian Smoothing filter is to what extent the filter reduces the deviation of the pixel values in the image between input and output. It was stated if there is more or less effect from the input.

❖ **Detect Edges by.** It is a dropdown button that gives users the ability to choose how the system will detect the edges in the Mark Area to Extract 3D Patterns Tool, in Section 4.4.4. The system provides two options for
detection, the Depth, and the RGB_Intensity. Depth uses the depth texture image from the camera to the 3D model mesh while the RGB_Intensity uses the colour differences image of the 3D model mesh, accordingly always to the 3D parallelepiped and its inner green plane.

❖ **Resolution X.** Defines the orthographic camera resolution on the x-axis.

❖ **Resolution Y.** Defines the orthographic camera resolution on the y-axis.

C. **Trackball Camera (F1) (Figure 55) (Available if Trackball camera is enabled)**

❖ **Movement Speed.** The speed movement of the Trackball Camera using mouse left-clicks.

❖ **Distance Cam. & Model.** The distance of the Trackball camera from the 3D model mesh.

❖ **Zoom Speed.** The zoom speed of the Trackball Camera using the scroll of the middle mouse wheel.

D. **FreeLook Camera (F2) (Figure 56) (Available if FreeLook camera is enabled)**

❖ **Movement Speed.** The speed at which the FreeLook Camera moves, through the use of the preset keys of the keyboard.

❖ **Fast Movement Speed.** The speed at which the FreeLook Camera moves through the use of the pressed 'Shift' key and one of the predefined keys of the keyboard.

❖ **Camera Speed.** The speed at which the FreeLook Camera moves through the use of the mouse, with the left click and its movement.

❖ **Zoom Speed.** The zoom speed on the FreeLook Camera using the scroll of the middle mouse wheel.

❖ **Fast Zoom Speed.** The zoom speed on the FreeLook Camera by pressing the 'Shift' key and using the scroll of the middle mouse wheel.
Figure 53: General Settings options.

Figure 54: 3D Pattern Extraction Algorithm Settings options.

Figure 55: Trackball camera Settings options.
The buttons Menu provided by the system in Settings Options (Figure 57) have a Tooltip feature and are as follows:

A. **Delete All Simple Annotations** button (Always available)
   This function deletes all annotations in the Simple Annotation Tool (Section 4.4.2). If there are no annotations noted in the 3D model mesh from this Tool, the 'Delete All Simple Annotations' button is disabled.

B. **Delete All Path Finder Annotations** button (Always available)
   This function deletes all annotations in the Path Finder Annotation Tool (Section 4.4.3). If there are no annotations noted in the 3D model mesh from this Tool, the 'Delete All Path Finder Annotations' button is disabled.

C. **Delete All 3D Pattern Extraction Annotations** button (Always available)
   This function deletes all annotations in the 3D Pattern Extraction Annotation Tool (Section 4.4.5). If there are no annotations noted in the 3D model mesh from this Tool, the 'Delete All 3D Pattern Extraction Annotations' button is disabled.

If one of these three buttons will be pressed, the system will pop up an appropriate confirmation window (Figure 58).
Figure 57: Buttons Menu in Settings Options.

Figure 58: Pop-up confirmation window ‘Are you sure you want to Delete ALL Simple Annotations?’ for annotations in the Simple Annotation Tool.
4.4 3DMA Tools

4.4.1 Inspection Tool

Description

The inspection Tool is activated at the start-up of the system after a model is being loaded. The system provides the ability to inspect a 3D loaded model, using one from the two existing cameras, either the Trackball camera or the FreeLook camera. Both cameras project to the scene with Perspective projection [38] [39]. Additionally, Trackball and FreeLook cameras have X, Y, Z boundaries in the 3D scene space, so that the 3D model does not stray too far from the screen view.
Trackball Camera Visualization

The Trackball camera is automatically activated at the application start-up step. In case, it is deactivated, the user can manually activate it, by pressing the 'F1' keyboard key. The inspection can be achieved using the mouse left and middle clicks and middle scrolls. The mouse relocation together with a continuously pressed mouse middle click can relocate the Trackball camera in the scene, directional to the mouse axes. The mouse middle scroll zooms in or out in the 3D scene, by moving the Trackball camera, depending on the direction of the scroll. Continuously pressed mouse left-click together with mouse relocation, will rotate the Trackball camera to the mouse directional axes around the Camera’s anchor, in a circular orbit. The Camera’s anchor is initially located in the centre of the 3D Model mesh. If the camera is relocated, using the pressed and relocated mouse middle-click, the Camera’s anchor will change accordingly to the directional to the mouse axes.

FreeLook Camera Visualization

The FreeLook Camera is activated with the 'F2' keyboard key. Inspection with FreeLook camera can be achieved using the mouse left-clicks and middle-scroll and seven keyboards keys. The continuously pressed mouse left-click while moving the mouse in the screen space is the anchor where the camera will be rotated and relocated through the keyboard keys. If the mouse left-click is not continuously pressed, the keyboard keys are still working. However, in this case, the camera can only be relocated, along its own p point centre through the keyboard keys. The mouse middle...
scroll zooms in or out in the 3D scene, by moving the FreeLook camera, depending on the direction of the scroll.

The 7 Keyboard keys are:

<table>
<thead>
<tr>
<th>Key</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q</td>
<td>Moves FreeLook camera Up relative to the 3D model (in the y-axis)</td>
</tr>
<tr>
<td>E</td>
<td>Moves FreeLook camera Down relative to the 3D model (in the y-axis)</td>
</tr>
<tr>
<td>W</td>
<td>Moves FreeLook camera In relative to the 3D model (in the z-axis)</td>
</tr>
<tr>
<td>S</td>
<td>Moves FreeLook camera Out relative to the 3D model (in the z-axis)</td>
</tr>
<tr>
<td>A</td>
<td>Moves FreeLook camera Left relative to the 3D model (in the x-axis)</td>
</tr>
<tr>
<td>D</td>
<td>Moves FreeLook camera Right relative to the 3D model (in the x-axis)</td>
</tr>
<tr>
<td>Shift</td>
<td>Speed all above actions</td>
</tr>
</tbody>
</table>

**Use Case**

As a continuation of the Use Case in Section 4.3.3, the user wants to check how the Trackball and the FreeLook camera work. Since the Trackball camera is activated by default, the user reallocates, rotates, and scales the camera in the 'krnhn.3dma' project, firstly via the Trackball Camera. Next, the user presses the 'F2' keyboard key to activate the FreeLook camera to make, once again, a relocation, a rotation, and a scale in the camera, via FreeLook camera this time.
Relocation, Rotation, and Scale using the FreeLook and Trackball cameras

The stages of Relocation, Rotation, and Scale using the FreeLook and Trackball cameras are:

**Step 1:** Initially, the user scales the Trackball camera relative to the 3D scene, by zooming out, using the middle mouse scroll.

![Figure 61](image)

Figure 61: Step 1 of the 'Relocation, Rotation, and Scale using the FreeLook and Trackball cameras'.

**Step 2:** For the camera Relocation to the left, the user continuously presses the middle mouse button and relocates the mouse from left to right.

![Figure 62](image)

Figure 62: Step 2 of the 'Relocation, Rotation, and Scale using the FreeLook and Trackball cameras'.
**Step 3:** Next, the user relocates the mouse from right to left while he/she continuously presses down the mouse's left-click to rotate the Trackball camera, by -90 degrees on the x-axis, into the 3D scene.

![Figure 63: Step 3 of the 'Relocation, Rotation, and Scale using the FreeLook and Trackball cameras'.](image)

**Step 4:** As a next step the user decides to try the FreeLook camera so he/she presses the 'F2' keyboard key. The user presses the 'Frame' button from Settings (Section 4.3.7) to frame the 3D Model mesh. After, the user scales the FreeLook camera relative to the 3D scene by zooming out, using the middle mouse scroll, just like in Step 1.

![Figure 64: Step 4 of the 'Relocation, Rotation, and Scale using the FreeLook and Trackball cameras'.](image)
**Step 5:** Afterwards translates the camera to the left into the 3D scene, by holding down for a few seconds the 'A' keyboard key.

![Figure 65: Step 5 of the 'Relocation, Rotation, and Scale using the FreeLook and Trackball cameras'.](image)

**Step 6:** Finally, the user rotates the FreeLook camera, by 90 degrees on the x-axis, by holding down the 'A' keyboard key and the mouse left-click while relocates the mouse from left to right, in the 3D scene. To get the 3D model closer to the camera, he/she presses for a few seconds the 'W' key.

![Figure 66: Step 6 of the 'Relocation, Rotation, and Scale using the FreeLook and Trackball cameras'.](image)
4.4.2 Simple Annotation Tool/Mode

Description
An annotation Tool enables where \( p \) points (over a 3D model mesh) are selected by the user to associate an annotation with them. A Mode of operation allows the user to repeatedly select points in a meaningful way, that are connected with a three-dimensional straight line per two points, forming a Group Annotation. This is succeeded using the metaphor of drawing a contour on the surface of this 3D object. In this case, the annotation is associated with a Group Annotation of 3D points produced by this Tool. Additionally, an annotation can consist only of one \( p \) point on the 3D model mesh and it is called Point Annotation.

Input
A 3D model in the form of a 3D mesh of triangles is provided where the user can interact to make notes or modify existing ones. Additionally, the user clicks in GUI, mouse clicks and keys 'A', 'Q', 'W', 'E', 'S', 'D', 'Shift', 'Left Alt' from the keyboard are inputs provided by the user.

Output
As an output, the Simple Annotation Tool provides Point or Group collections of 3D \( p \) points represented as red 3D spheres primitives. Each Group that consists of more than two 3D red spheres, contains a three-dimension straight line per two 3D red spheres. Additionally, the visualization is an equally important output and it is described below.

Visualization
While using this Tool, Point Selection Mode is enabled, the Inspection Mode is disabled and Annotation upon a 3D mesh is possible. The Point Selection Mode enables the application possibility of the Point Selection Algorithm. To reverse the Inspection Mode, users can press the key 'Left Alt' from the keyboard. To return in the Point Selection Mode key 'Left Alt' must be pressed once more. This option exists for the easier use of this Tool. The system creates primitives to visually mark the annotated \( p \) points for the user and, through them, allows the editing of the selected \( p \) point. These \( p \) points selection is conducted by the Point Selection Algorithm (in Section 4.4.2, in Methods) and each \( p \)
point has Point Editing Options (in Section 4.4.2). The \( p \) point at which the mouse points, belongs to a point over a \( T \) triangle from the 3D model mesh. This \( T \) triangle appears with a yellow border for a better understanding and accuracy of the potential \( p \) point to be selected. Simple Annotation Tool provides three categories of Annotations, Point Annotation (consists of one \( p \) point), Group Annotation (consists of \( n_i > 1 \) \( p \) points) and Pen Group Annotation (consists of \( p \) points, \( n_{pi} > 1 \) and \( n_{pi} > n_i \)), which belongs in the Group category.

In Point Selection Mode, the user can place unlimited spheres on a 3D mesh. Placement can be done in two ways, either by the \( c \) point indicated by the mouse in combination with the 'A' pressed keyboard key or by a \( c \) mouse left-clicking on a \( T \) triangle of the 3D model mesh. As long as the 'A' button is pressed (constantly or not), a sphere is placed at the point where the mouse is ray casting if the mouse points over the 3D mesh. The primitives are presented in the form of red 3D spheres. If a sphere is selected (by left or right-clicking on the sphere) the selected primitive changes its colour from red to blue. Sphere’s colour can be restored from blue to red by double-clicking in an area out of the 3D mesh.

When multiple points are created, these spheres are connected with a black three-dimensional straight line from one sphere to another and forms a Group. This line can penetrate through the 3D model mesh depending on the placement of the 3D \( p_i \) points. If a Group contains 'Group Description' ((2) in Point Editing Options, in Section 4.4.2), the black three-dimension straight-line changes its colour from black to yellow. If a red 3D sphere contains 'Point Description' ((3) in Point Editing Options, in Section 4.4.2), it changes its colour from red to yellow.

A Group Annotation remains active if and only if it is not closed. We name a Group as active when other spheres can be added. While it is active, all Group spheres are connected with the black three-dimensional straight line, except the first and the last. The system has the option to close the Group by Point Editing Options ((1) in Point Editing Options, in Section 4.4.2) or by pressing the first placed 3D primitive into that Group with mouse left-click. When a Group closes, a 3D line will connect the first and the last sphere. After closing a Group, adding a new sphere will signal the creation of a new Group Annotation. A Group consists of two or more spheres (3D \( p_i \) points). If a Group Annotation consists of one 3D \( p \) sphere, it is called Point Annotation and has the corresponding editing options.

For every new change that has been made, the system provides two options, either to storage or to discard the new changes. These two options are presented in the form of buttons in the panel, on the upper left side. Unless there is a new change, these two buttons are deactivated and cannot be pressed.
**Point Editing Options**

All Simple Annotations have editing options. To access these options, a red sphere primitive must be selected with a right-click. Then a primitive changes its colour from red to blue, indicating that it is selected. A 3D point can be selected irrespective of whether the selected 3D sphere is in an active Group.

These options are represented in the form of buttons in a circular Menu, have a Tooltip feature, and are as follows:

1. **Close Group/Point.** This button connects the first with the last sphere primitive, in the existing Group that blue sphere belongs, with a three-dimension straight line, and closes the Point Editing Options Menu. If the Group consists only of one primitive, it is called Point and closes the ability to add any more primitives into that Point.

2. **Group Description.** Group Description button opens the Group Description Window (Figure 69) for the selected Group to add text or edit the existing one and closes the Point Editing Options Menu. When the Group description is added and it’s not empty, the black three-dimension straight line turns its colour from black to yellow. If a Group has a Group description and one of its primitives is selected, the Group Description Window will open.

3. **Point Description.** This button opens the Point Description Window (Figure 68) for the selected point to add text or edit the existing one and closes the Point Editing Options Menu. When Point description is added and it’s not empty, the blue primitive turns its colour from blue to yellow. If a Point primitive has a Point description and is selected, the Point Description Window will open.

4. **Delete Point.** This button deletes the selected primitive and closes the Point Editing Options Menu.

5. **Delete Group.** Delete Group button deletes the Group Annotation of the selected primitive and closes the Point Editing Options Menu.

6. **Move Point (Point Relocation Mode).** This button relocates the selected primitive to another position. When this button is pressed, the Point Editing Options Menu closes and gives the ability to the user to select another position to place the selected primitive. The selection of the new position is done by mouse left-clicking on the desired point of the 3D model mesh. As long as the Point Relocation Mode
is enabled, the system displays an appropriate text indication (‘Click to Relocate the Selected Sphere’) below the mouse cursor.

7. **Close Menu.** Close Menu button closes the Point Editing Options Menu.

![Point Editing Options Menu](image1)

**Figure 67:** Point Editing Options Menu in the Simple Annotation Tool (Section 4.4.2).

![Point Description Window](image2)

**Figure 68:** Point Description Window.
Methods

Point Selection Algorithm

The Point Selection Mode enables the application possibility of the Point Selection Algorithm.

The c point indicated by the mouse in combination with the 'A' pressed keyboard key or user left-clicks, are ray-casted from screen space to 3D space to find the location that the user intends to select. The screen image is a rendering of the image that would be acquired from a virtual camera, located at some virtual world point C and oriented as rotation matrix R denotes for the particular camera pose.

This works as follows (scenario):

The user clicks on pixel c in the screen image. A ray begins from point C and passes through pixel c. Let v the direction of the ray. The ray equation is in essence a line equation that can be expressed as L(s) = C + v*s.
This line may or may not intersect the mesh. If it does not, a null result is returned. If it does, the intersection of the line with the front most triangle of the mesh, as determined by depth ordering from the particular camera pose, is found. Then, the intersection point of the triangle with this line is calculated. The aforementioned functionality is implemented through the Physics Ray cast provided by Unity, triangle intersection can be found. In our implementation, a requirement for collisions is that meshes have Collider components (mesh, box, etc.).

Point Annotation

Point Annotation is one closed \( p \) point, using the Point Selection Algorithm from Methods in Section 4.4.2. This point is selected through the Point Selection Mode, using the mouse a left-click or presses of keyboard key 'A'. The closed \( p \) point is represented as one red 3D sphere primitive.

Group Annotation

Group Annotation is a closed Group with multiple points \( (p_j, n_j > 1) \), connected with a three-dimensional straight line. These points \( p_j \) are represented as red 3D spheres primitives. They are selected in sequential order, repeatedly using the Point Selection Algorithm from Methods in Section 4.4.2, through the Point Selection Mode. Additionally, the 3D multiple \( p \) points are selected using mouse left-clicks or presses of keyboard key 'A'.

Pen Group Annotation

Pen Group Annotation is a closed Group Annotation consisted of \( p_i, n_{pi} > 1 \) points with \( n_{pi} > n_i \). These points \( p_i \) are represented as red 3D spheres primitives. Pen Group Annotation uses mouse left-clicks, like the Group Annotation in the previous paragraph, or the continuous press of the key 'A' from the keyboard. While key 'A' is continuously pressed, Point Selection Algorithm from Methods in Section 4.4.2 is activated, through the Point Selection Mode, forming points in a row. This makes the impression of freestyle pen lines and contours.

Use Cases

Let’s suppose that the users have a false murder scene scenario that took place at the University of Computer Science in Heraklion, Crete. This scene includes a dead man on the floor. His body was whole and his head was on a broken laptop. Inside the room, it was found a bed with sheets, a hammer, some debris, and a grey piece of furniture.
The hammer was probably the murder weapon. Blood was splatted in three places: on the wall, on the floor, and the broken laptop near the dead’s body head. The body was successfully identified as Mr Luca Riza. The policemen discovered that he is a well-known PhD candidate at the University of Computer Science and an early-stage researcher in the field of artificial intelligence. The room was probably Mr Riza’s secret workshop. The grey furniture in the murder room contained encoded hard drives in a hidden location inside the furniture. Fingerprints of two people incl. Mr Riza and an unrecognized woman were found, on the right outside side of the grey furniture. The same unknown prints were found on the bedsheets. Greek police have not been able to find the identity of the second person who is likely to be the perpetrator. No other contents were found on the grey furniture. The target was presumably the contents of the grey furniture. The perpetrator did not realize in his rush for the hidden case and so the hard drives were found intact.

Use Cases:

A. **Point Annotation** (using the Method Point Annotation from Section 4.4.2). First mark with a Point Annotation in the area where the hammer and the debris were found and add a small Point description in each point.

B. **Group Annotation** (using the Method Group Annotation from Section 4.4.2). Using the Group Annotation, show the three points of blood by adding a Group description.

C. **Pen Group Annotation** (using the Method Pen Group Annotation from Section 4.4.2). Create an annotation using the Pen Group Annotation to show where the fingerprints were found, and add a Group description.
Point Annotation

Suppose that there is a user who wants to mark with a Point Annotation the area where the hammer and the debris were found, and add a small text description in each point.

**Step 1:** As a beginning, the user should go to the inspection Tool and adjust the Trackball camera, in a position that has the desired visibility of the hammer or debris. Let's assume that the user decides to focus on the hammer first. Additionally, the user closes the Settings Options.

![Figure 70: Step 1 of the 'Point Annotation'.](image)

**Step 2:** The user should select the Simple Annotation Tool and make a left-click on the hammer or somewhere near it, to determine the point. A red primitive sphere will be created at the point where the left-click was made.

![Figure 71: Step 2 of the 'Point Annotation'.](image)
**Step 3:** Right-clicking on the red sphere, that has just been created, will change the colour of the sphere from red to blue and will open the Point Editing Options Menu.

![Figure 72: Step 3 of the 'Point Annotation'.](image)

**Step 4:** The user selects the "Close Point" option and will notice that the Point Editing Options Menu will close. This means that the Point Annotation is closed, and it consists of a single sphere.

![Figure 73: Step 4 of the 'Point Annotation'.](image)
**Step 5:** The user opens the Point Editing Options Menu again in the same way and this time selects the 'Point Description' option. The Menu closes, but this time the Point Description Window will open for adding Point description.

![Figure 74: Step 5 of the 'Point Annotation'.](image)

**Step 6:** In this window, the user writes "Possible Murder Weapon" and presses the 'Save Changes' button. Automatically the text info will be attached in the sphere and the Point Editing Options Menu will close. Also, the blue sphere will change its color from blue to yellow, showing that this sphere has a Point description.

![Figure 75: Step 6 of the 'Point Annotation'.](image)
**Step 7:** The User wants to do the same procedure for the debris but noticed that the view is not convenient and wants to change it. In this case 'Left Alt' is pressed. With this action, the Inspection Mode is activated and the Point Selection Mode is deactivated. The user could choose to go to the Inspection Mode to do this, but this shortcut was added to the system for faster use of the Tool. Using the Trackball camera as before, the user changes the angle of view to a convenient one.

![Figure 76: Step 7 of the 'Point Annotation'.](image)

**Step 8:** Pressing 'Left Alt' once more the system will exit the Inspection Mode and Point Selection Mode is going to be enabled.

![Figure 77: Step 8 of the 'Point Annotation'.](image)
**Step 9:** Then the user acts exactly as before by placing a red primitive in the middle of the debris and add the Point description "Debris Ignore this area" to it.

![Figure 78: Step 9 of the 'Point Annotation'.](image)

**Step 10:** The user presses the 'Save Changes' button to save the text description and attach it to the new Point Annotation. The Point Description Window will close and the 3D sphere primitive will change its color from blue to yellow. All these changes are not saved unless the corresponding save changes button provided by the system is pressed. The user’s final action is to press the 'Save Changes' button. If he/she does not want to save the changes but prefers to ignore them, the reset option is provided by the system, through a button next to the save button on the top left-oriented panel.

![Figure 79: Step 10 of the 'Point Annotation'.](image)
**Step 11 (Info):** If a yellow primitive is pressed with mouse left-click, it will turn blue, and the Point Description Window will open with the attached description to it, for convenient reading and editing.

**Group Annotation**

Assuming that the user wants to note more details of the murder scene, as a continuation of the previous Use Case (Point Annotation) in Section 4.4.2. He/she wants to place a Group Annotation, connecting the three points where the blood spots were observed.

**Step 1:** At first the user has to press again the 'Left Alt' key to activate the Inspection Mode. He/she redirects the camera position into a position that serves him/her so that the three points of blood are visible. After the repositioning of the camera, the user presses the 'Left Alt' key again to deactivate the Inspection Mode and activate the Point Selection Mode.

![Figure 80: Step 1 of the 'Group Annotation'.](image-url)
**Step 2:** The user presses one by one the three points where the blood of Mr Riza was found. Three red spheres will be created in each pressed point as well as a black three-dimensional straight line from sphere to sphere, except for the first and the last.

![Figure 81: Step 2 of the 'Group Annotation'.](image)

**Step 3:** This means that the Group is active and not closed. There are two ways to close this Group and create a black three-dimensional straight line between the first and the last sphere primitive. Either with mouse left-clicking, by clicking the first placed sphere in the current Group, either with the ‘Close Group’ button from the Point Editing Options Menu. The user selects the second option, so he/she right-clicks one of the three spheres to open the Point Editing Options Menu.

![Figure 82: Step 3 of the 'Group Annotation'.](image)
**Step 4:** The user finds and presses the 'Close Group' option. The Menu will close and a black three-dimensional straight line will be created between the first and last primitive. This means that the Group is no longer active and that it is closed. The thickness of the black three-dimension straight line can be changed from the Settings Options on the left side of the system.

![Figure 83: Step 4 of the 'Group Annotation'.](image)

**Step 5:** Next, the user wants to add a description for the whole Group. He/she will right-clicks on one of the three created spheres to open the Point Editing Options Menu and finds the 'Group Description' button.

![Figure 84: Step 5 of the 'Group Annotation'.](image)
Step 6: Next the user presses the 'Group Description' button. The Point Editing Options Menu will close and the Group Description Window will open to the right side of the 3DMA system.

Step 7: He/she writes 'Blood of Mr Riza' and presses the 'Save Changes' button. The Group Description window closes, the text is registered into the Group, and the black three-dimensional straight line of the Group changes its colour from black to yellow.
Step 8: Finally, to save the total changes that the user has done so far, he/she must press the 'Save Changes' button located on the top left-oriented panel. When the 'Save Changes' button is pressed, it is deactivated as an indication that there are no new changes.

Pen Group Annotation

As a final Use Case, the user will create two new Pen Group Annotations (using the Pen Group Annotation Method) to circle the two areas where the unidentified fingerprints were found, as a continuation of the previous Use Case (Group Annotation) in Section 4.4.2. These two points are on the sheets at the bottom of the bed and the right side of the grey furniture.

In this scenario, almost the same steps are followed as before (Group Annotation Use Case in Section 4.4.2). The only difference between Group and Pen Group Annotation is that in the latter one the user constantly presses the 'A' keyboard key and moves the mouse circularly around the area he/she wants to mark. This makes the impression of a circular line, hence the name, Pen Group Annotation.
4.4.3 Path Finder Annotation Tool/Mode

Description

The Path Finder Annotation Tool enables the user to repeatedly selects 3D points of a 3D model mesh in a meaningful way, on the surface of a 3D model mesh. It is quite similar to the Simple Annotation Tool (Section 4.4.2) but it mainly differs in the connection of the 3D selected Points. The connection is made with the shortest Geodesics [41] three-dimension lines paths on the 3D mesh, per two 3D points, instead of the Simple Annotation Tool where there are three-dimension straight lines between these points.

Input

A 3D model in the form of a 3D mesh of triangles is provided, in which users can interact to make annotations or modify existing ones. Additionally, the user clicks in GUI, mouse clicks and keys 'A', 'Q', 'W', 'E', 'S', 'D', 'Shift', 'Left Alt' from the keyboard are inputs provided by the user.

Output

As an output, the Path Finder Annotation Tool provides Group collections of 3D points that are represented as purple 3D spheres primitives. Each Group is consisted
of more than two 3D purple spheres and contains a Geodesics connection per two purple spheres.

**Visualization**

Once the Path Finder Annotation Tool is enabled, the Point Selection Mode is also enabled, making the point selection upon a 3D mesh possible, while the Inspection Mode is disabled. For easier use of the Tool the 'Left Alt' keyboard key must be pressed, to enable the Inspection Mode, without changing the Tool. If the users wish to return to the Point Selection Mode, the 'Left Alt' keyboard key must be pressed once more.

The system creates primitives to visually mark the annotated points for the user and, through them, allows the editing of the selected points. These points selection is conducted by the Point Selection Algorithm (in Section 4.4.2, in Methods) and each point has Point Editing Options (in Section 4.4.3). The point at which the mouse cursor points out belongs to a T triangle from the 3D triangulated model mesh. This T triangle appears with a yellow border for a better understanding and accuracy of the potential point to be selected. Path Finder Annotation Tool provides only Group Annotations (consists of \( n_i > 1 \) points).

In the Path Finder Tool, during the Point Selection Mode, the user can place unlimited spheres on the 3D mesh. The points placement can be done by a mouse left-click on a T triangle of the 3D model mesh. The primitives are represented in the form of purple spheres. If a sphere is selected (by clicking on the sphere), its colour change from purple to blue. Sphere colour can be restored from blue to purple by double-clicking in an area out of the 3D mesh, in the 3D scene. In every purple primitive Point description (through the Point Editing Options (Section 4.4.3)) can be added. If a purple 3D sphere contains 'Point Description' (option three (3) in Point Editing Options, in Section 4.4.3), its colour turns yellow.

When multiple points are created, these spheres are connected into a black three-dimensional Geodesic line from one sphere to another and forms a Group. If a Group contains 'Group Description' ((2) in Point Editing Options, in Section 4.4.3), the black three-dimension Geodesic line changes its colour from black to yellow.

The three-dimensional Geodesic line between two 3D purple primitives computes and displays the shortest path of the 3D triangulated model mesh using the Dijkstra algorithm. Dijkstra algorithm relies on the edges of the 3D triangulated mesh; edges which are parts of the final path of the three-dimensional Geodesic line between two 3D points.

A Group does not close as long as it is active. We name a Group as active in which when other spheres can be added. While Group is active all spheres are connected with the black three-dimensional Geodesic line, except the first and the last. The
system has the option to close the Group by Path Finder Editing Options ((1 in Point Editing Options, in Section 4.4.3) or by pressing the first placed 3D purple primitive into that Group with mouse left-click. When a Group closes, a 3D Geodesic line will connect the first and the last sphere. After the Group is closed, adding a new sphere will signal the creation of a new Group. A Group may consist of two or more 3D purple primitives. This Tool allows only Group Annotations.

For every new change that has been made, the system provides two options, either to storage or to discard the new changes. These two options are in the form of buttons in the panel, on the upper oriented left side of the panel. Unless there is a new change these two buttons are deactivated and cannot be pressed.

In addition, two cases should be noted. Firstly, in case the user creates a group with a single purple sphere and presses the 'Save Changes' button he/she will receive a pop-up window emphasizing that 'Active Path Finder Annotation Group with one primitive will not be saved' (Figure 89). This is because this Tool accepts only Group creations. The second has to do with the three-dimensional Geodesic line between two 3D points. In case the 3D model is not completely connected, e.g. consists of pieces of 3D meshes, there is a case that no path can be found between the selected p point and its previous p point of the Group. In this case, the system informs the user accordingly (Figure 90).

Figure 89: Pop-up information window 'Active Path Finder Annotation Group with one primitive will not be saved.'.

Figure 90: Pop-up information window 'Path was not found.'.
Point Editing Options

Point Editing Options in the Path Finder Annotation Tool are the same as the Point Editing Options in the Simple Annotation Tool (in Point Editing Options, in Section 4.4.2). These options are (1) **Close Group/Point**, (2) **Group Description**, (3) **Point Description**, (4) **Delete Point**, (5) **Delete Group**, (6) **Move Point**, and (7) **Close Menu**.

Method

Group Annotation

Group Annotation is a closed Group with multiple points \( p_i, n_i > 1 \), connected with a three-dimensional Geodesic line. They are repeatedly selected in sequential order, using the Point Selection Algorithm in Section 4.4.2, through the Point Selection Mode, via mouse left-clicks. These \( p_i \) points are represented as purple 3D spheres primitives.

Use Case

As a continuation of the previous Use Case in Section 4.4.2, and after further investigation some blond hairs were found under and above the red plug, on the lower left-oriented side of the room. After DNA tests, it was found that the hair belongs to Miss Hortensia Cantrea, a Mr. Riza’s student, who is the main suspect of his murder so far.

Using the Path Finder Annotation Tool, the user will annotate the area in which that clue was found and will also make a brief description of Miss Hydrangea Cantrea, in the Group marked area, that she is considered the main suspect of Mr. Riza.
Group Annotation

The stages of the Group Annotation of the area in which the blond hair was found is:

**Step 1:** The user opens the murder scene in the 3DMA system and closes the Settings Options.

![Figure 91: Step 1 of the 'Group Annotation'.]

**Step 2:** Through the Inspection tool, the user adjusts the Trackball camera appropriately to a position that serves him/her, for annotating the desired area and selects the Path Finder Annotation Tool.

![Figure 92: Step 2 of the 'Group Annotation'.]
**Step 3:** The user presses four points to create a Group Annotation for the area where the blond hair of Miss Hortensia Cantrea was found. After the first point, for each new pressed point, the system needs a few seconds to calculate the Geodesic path through the triangulated mesh. Until the system finds the shortest path through Dijkstra Algorithm, it displays an appropriate message 'Please wait'.

![Figure 93: Step 3 of the 'Group Annotation'.](image)

**Step 4:** Four purple spheres are created in each pressed point as well as a black three-dimensional Geodesic line from one sphere to another, except the first and the last primitive. The first and the last purple sphere are not connected because the Group is active and not closed.

![Figure 94: Step 4 of the 'Group Annotation'.](image)
Step 5: There are two ways for the user to close this Group, and create a black three-dimensional Geodesic line between the first and the last purple sphere. Either with mouse left-click, by clicking the first placed sphere in the current Group, or by the 'Close Group' button from the Point Editing Options Menu. The user selects the second option, so he/she right-clicks one of the four purple spheres to open the Point Editing Options Menu. Then he/she notices that the selected sphere changes its colour from purple to blue and that opens the Point Editing Options Menu. The user finds the 'Close Group' option.

![Figure 95: Step 5 of the 'Group Annotation'.](image1)

Step 6: The user presses the 'Close Group' option. The Menu will close and a black three-dimensional Geodesic line will be created between the first and last purple primitive. This means that the Group is no longer active and that it is closed.

![Figure 96: Step 6 of the 'Group Annotation'.](image2)
Step 7: Next the user wants to add a description for the whole Group, so he/she hits on one of the four created purple spheres with the right-click to open the Point Editing Options Menu and finds the ‘Group Description’ option.

Step 8: The user presses the 'Group Description' button. The Point Editing Options Menu will close and the Group Description Window will open to the right-oriented side of the system. The user adds the description 'Blond hair of Miss Hortensia Cantrea was found here. She is the main suspect in this case.'
**Step 9:** The user presses the button 'Save Changes' below to save it. The Group Description window closes and the text is registered into the Group. The black three-dimensional Geodesic line of the Group changes its colour from black to yellow.

![Figure 99: Step 9 of the 'Group Annotation'.](image)

**Step 10:** Finally, in order user to save the total edits that he/she has done so far, he/she must press the 'Save Changes' button located on the panel. When the 'Save Changes' button is pressed it is deactivated as an indication that the new changes are been saved and there are no new ones.

![Figure 100: Step 10 of the 'Group Annotation'.](image)
4.4.4 Mark Area to Extract 3D Patterns

Description

For users to extract 3D patterns in a specified area, they need to mark and determine the desired area. To do that, the 3DMA system provides the Mark Area to Extract 3D Patterns Tool, which helps the users to specify that area. It provides the functionality of adding in the 3D scene, a 3D grey transparent parallelogram with an inner plane inside of it, with relocation, resizes, and rotation abilities. According to the 3D parallelogram, the users can execute the 3D Pattern Extraction Algorithm, which is analyzed below in Section Method.

Input

A 3D model in the form of a 3D mesh of triangles is provided, the user clicks in GUI, as well as, the keyboard keys 'A', 'D', 'Q', 'E', 'W', 'S', 'Shift', 'Left Alt', 'B', 'N', 'M', 'L' which are inputs provided by the user.

Output

As an output, the Mark Area to Extract 3D Patterns Tool provides a 3D grey transparent parallelogram with one integrated plane inside of it. Moreover, the system contains a raw image texture for the potential detect edges, a Group/s of 3D p points represented as green 3D spheres primitives (3D extraction pattern), and two '.png' images (Depth Texture and Edges Texture) for each 3D extracted pattern.

Visualization

The Mark Area to Extract 3D Patterns Tool allows users the ability to create or delete and reposition, one three-dimensional parallelepiped with a built-in green plane in the middle. The parallelogram’s creation can be done either by a Menu, the Parallelogram Editing Options (in Section 4.4.4) via a button, or by a mouse left-click using the Point Selection Mode. Additionally, irrespectively of the way of creation, the parallelogram is being rotated according to the camera’s rotation and has specific dimensions. The system gives users the ability to manually rotate, reposition and resize a created parallelogram through Transform Gizmo visualization [38] [39]. The inner parallelogram’s plane can be manually shifted, but only parallel to the z-axis relative to the 3D parallelogram, in the range of 'ParallelogramHeight'.
The Plane Relocation Mode can be enabled only by the Parallelogram Editing Options Menu. Parallelogram Rotation, Reposition and Resize Mode can be enabled by using a specific keyboard key or through the Parallelogram Editing Options Menu. The Parallelogram Editing Options Menu can be opened with a right-click, in any point position of the screen space.

In this Tool, the Inspection Mode is enabled, unless if one of the above Modes is enabled or the parallelogram is not yet created. If the parallelogram hasn’t been created, the Point Selection Mode is enabled, for the manual placement of the parallelogram. If a Mode is enabled, then the Inspection Mode is deactivated. Nonetheless, the system provides the users with the ability to activate the Inspection Mode via the 'Left Alt' keyboard key. Thus, if the 'Left Alt' key is pressed (while a Mode is active or the parallelogram is not yet created), the current Mode will be deactivated, until the 'Left Alt' key is pressed once again.

The utility of the internal layer is to efficiently define the desired area in order to execute the 3D Pattern Extraction Algorithm (in Method Section 4.4.4). This surface is green on one side and grey on the other. The green side defines the 3D area that the 3D Pattern Extraction Algorithm will use to calculate the final edge points and has been implanted for better orientation. It is also important to mention that the algorithm does not take into account the 3D model mesh that exists underneath the green plane.

After the parallelogram’s placement at the desired position and its inner plane at the desired level respectively, the system provides a 2D live preview of the possible final edges in the form of a black image with red pixels. These pixels represent the potential detect edge points of the 3D Pattern Extraction Algorithm execution. The two-dimensional image appears on the lower right side of the system and is generated by the 3DMA system’s GPU according to a variety of variables. These variables exist and can be edit by users in the Settings Options (‘3D Pattern Extraction Algorithm’ in Section 4.3.7).

After the successful parallelogram formatting, its internal layer and the finalization of the '3D Pattern Extraction Algorithm' variables, in the Settings Options, are able, (through the Parallelogram Editing Options (in Section 4.4.4)), to execute the 3D Pattern Extraction Algorithm. This algorithm calculates and finds the edges of the marked area. Next, the system creates a Group of primitives to visually mark the edges points of the 3D extracted pattern for the users. These primitives are represented in the form of 3D green spheres. For further processing of the 3D extracted pattern, users must proceed to the 3D Pattern Extraction Annotation Tool/Mode (Section 4.4.5). At the same time, the 3D Pattern Extraction Algorithm produces two '.png' images for the 3D extracted pattern. The first image represents the 3D extracted pattern to a 2D Depth/RGB_Intensity Texture image and the second to a 2D pixel detect Edges Texture image. When these two '.png' images are produced, the system displays in the 2D screen an appropriate information pop-up
window, with the respective path that the two images have been saved (Figure 101). Users can execute the 3D Pattern Extraction Algorithm in every 3D location of the 3D model mesh through the 3D parallelogram as many times as they wish.

Two new PNG Images (Depth Texture, Edges Texture) were created in the:

C:\Users\mdouger\Desktop\3DMA (3D Model Annotator) - Doulgeraki Maria\3DMA - Project - Doulgeraki Maria\3D Meshes\Images_DetectEdges_Coin

Figure 101: Pop-up information window example of the creation of two ‘.png’ images and their path that are stored.

Parallelogram Editing Options

The 3D parallelogram with its inner plane has some editing options. Users should press a right-click, at any point of the 3D scene area, to access these options.

These options are represented in the form of buttons in a circular Menu, have a Tooltip feature, and are as follows:

1. **Add Selection Area.** This button creates a 3D grey transparent parallelogram with an integrated plane inside of it and closes the Parallelogram Editing Options Menu. The parallelogram’s point placement is the centre of the 3D model mesh, it is rotated according to the camera’s rotation and has specific dimensions.

2. **Delete Selection Area.** This button deletes the 3D parallelogram with its inner plane and closes the Parallelogram Editing Options Menu.

3. **3D Pattern Extraction.** The 3D Pattern Extraction button executes the 3D Pattern Extraction Algorithm and closes the Parallelogram Editing Options Menu. The green spheres primitives are placed in the 3D model mesh respectively the edges that were found.

4. **Lock (Lock Mode).** The Lock button enables the Inspection Mode and disables every other enabled Mode (Rotation Mode, Relocation Mode, Resize Mode, or
Plane Relocation Mode) and closes the Parallelogram Editing Options Menu. Lock Mode can be enabled also from keyboard key 'L'.

5. Move Plane (Plane Relocation Mode). This button enables the Plane Relocation Mode, disables the Inspection Mode, and closes the Parallelogram Editing Options Menu. As long as the Plane Relocation Mode is enabled, the system displays an appropriate text indication ('Plane Relocation Mode') below the mouse cursor. The relocation of the plane can be done in two ways either by using user mouse left drags or by keyboard keys 'W', 'S' and 'Shift'.

   - Keys 'W', 'S': Relocates the parallelogram's plane in the z directional axes of the parallelogram, in the range of 'ParallelogramHeight'.
   - Key 'Shift': Speeds the previous keys actions.

6. Move Selection Area (Relocation Mode). The Move Selection Area button enables the Relocation Mode for the parallelogram, it disables the Inspection Mode and closes the Parallelogram Editing Options Menu. The relocation of the parallelogram it can be done in two ways either by using Transform Gizmo with user mouse left drags or by keyboard keys 'A', 'D', 'W', 'S', 'Q', 'D' and 'Shift'. The Relocation Mode can be enabled also from key 'B' of the keyboard.

   - Keys 'A', 'D': Relocates the parallelogram in the x-axis.
   - Keys 'W', 'S': Relocates the parallelogram in the z-axis.
   - Keys 'Q', 'E': Relocates the parallelogram in the y-axis.
   - Key 'Shift': Speeds the previous keys actions.

7. Rotate Selection Area (Rotation Mode). This button enables the Rotation Mode for the parallelogram, it disables the Inspection Mode and closes the Parallelogram Editing Options Menu. The rotation of the parallelogram it can be done in two ways either by using Transform Gizmo with user mouse left drags or by keyboard keys 'A', 'D', 'W', 'S', 'Q', 'D' and 'Shift'. The Rotation Mode can be enabled also from key 'N' of the keyboard.

   - Keys 'A', 'D': Rotates the parallelogram in the x-axis.
   - Keys 'W', 'S': Rotates the parallelogram in the z-axis.
   - Keys 'Q', 'E': Rotates the parallelogram in the y-axis.
   - Key 'Shift': Speeds the previous keys actions.

8. Resize Selection Area (Resize Mode). This button enables the Resize Mode for the parallelogram, disables the Inspection Mode, and closes the Parallelogram Editing
Options Menu. The resize of the parallelogram it can be done in two ways either by using Transform Gizmo with user mouse left drags or by keyboard keys 'A', 'D', 'W', 'S', 'Q', 'D' and 'Shift'. The Resize Mode can be enabled also from key 'M' of the keyboard.

- **Keys 'A', 'D':** Resize the parallelogram in the x-axis.
- **Keys 'W', 'S':** Resize the parallelogram in the z-axis.
- **Keys 'Q', 'E':** Resize the parallelogram in the y-axis.
- **Key 'Shift':** Speeds the previous keys actions.

9. **Close Menu.** The Close Menu button closes the Parallelogram Editing Options Menu.

![Figure 102: Parallelogram Editing Options Menu in the Mark Area to Extract 3D Patterns Tool (Section 4.4.4).](image)

**Method**

**3D Pattern Extraction Algorithm**

3D Pattern Extraction Algorithm uses the well-known 'Canny Edges Detect' algorithm [42]. Canny edge detection is a multi-step algorithm that can detect edges with noise suppressed at the same time through a 2D image. The 3DMA system provides that image (Depth/RGB Intensity Texture 2D image) through an Orthographic Projection Camera in the green inner plane of the 3D parallelogram.
Canny Edges Detect Algorithm steps are as follows [43]:

1. **Apply a Gaussian blur.** Firstly, the necessary variables are declared and some are being initialized. Then a Gaussian blur is applied to the input image in Figure 103. To do this, a nxn (n = Kernel Diameter in Settings Options (Section 4.3.7)) mask is passed over the image. Each pixel is redefined as the sum of the pixel values, in its nxn neighborhood, multiplied by the corresponding Gaussian weight and divided by the total weight of the whole mask. The Blurring Effect value in Settings Options (Section 4.3.7) is the Standard Deviation, which determines how strong is the blurring effect. It can be used in conjunction with the kernel diameter to reject low-frequency lines early on.

   ![Figure 103](image1.png)

   **Figure 103:** Input image in the 3D Pattern Extraction Algorithm execution.

2. **Find edge gradient strength and orientation.** The next step is to use Sobel masks to find the direction and magnitude of change around each pixel of the blurred image, per axes. A Sobel mask is a 3x3 pixel neighbourhood where each cell
contains a weight of influence. The appropriate mask is used depending on the axes. For each pixel of the input image, Gx and Gy are calculated respectively by taking the sum of all pixel values in its neighbourhood, each of them multiplied by the corresponding weight in the mask. Finally, the gradient magnitude (or strength) for both axes is calculated by taking the square root of Gx squared plus Gy squared and the edge orientations are calculated by the inverse tangent of Gx / Gy yields the edge orientation.

![Gradient components](image)

Figure 105: After Step 2 in the 3D Pattern Extraction Algorithm execution.

3. **Suppress the non-maximum values by tracing along the edges**, as seen in the Gradient components. Edge detection needs the edges as seen from the Gradients, to be decreased down for further processing. Non-maximum suppression achieves this by capitalizing on the fact that lines can be seen as bell curve distributions where the maximum value of the curve is the point where the line pixel values peak along a line's width. For each pixel, the direction of change is calculated based on the inverse tangent of Gx / Gy yields. By adding (and subtracting) the normalized direction to the pixel coordinates of the current pixel, two points are produced, which lie on opposite sides of the line and are perpendicular to the line. Suppression of non-maximum values is achieved by testing the gradient strength of these two pixels against the current pixel. If the current pixel's gradient strength is higher than the two side pixels', then it is classified as a maximum and kept, while the rest of the pixels of the line are suppressed. The result will be a 1-pixel wide line. Furthermore, the first pass of threshold filtering occurs at this stage. The pixels which passed the magnitude test get tested once more against the Strong and Weak threshold. Pixels with a magnitude less than the Weak Threshold are discarded and set to 0.0f (normalized or RGB value range). Pixels with a magnitude greater than the Strong threshold are classified as Strong Edges and typically get a value of 1.0 (normalized) or 255(RGB value range). Any pixel whose gradient
magnitude lies between Weak and Strong thresholds is classified as a weak edge pixel and gets assigned a value of either 0.5(normalized) or 128(RGB).

4. The final stage of the edge detection process is **Hysteresis**, which is a recursive process where each pixel, that was previously classified as a weak edge pixel, is re-evaluated by testing its direct adjacency with known strong edge pixels. If direct adjacency exists, the pixel's classification is promoted to a strong edge. Every time weak edge pixels get promoted, the remaining weak edge pixels need to be retested, until no more can be promoted. The remaining weak edge pixels that cannot attain adjacency to a strong edge pixel, will eventually be discarded as background/void, by being set to 0.
Section 4.4.2) to place in each ep point a 3D green sphere primitive to a depth accordingly the Depth/RGB_Intensity Texture 2D image, that produced from the Orthographic Projection Camera. Additionally, the 3D Pattern Extraction Algorithm produces two '.png' images for the 3D extracted pattern. The first image represents the 3D extracted pattern to a 2D Depth/RGB_Intensity Texture image and the second to a 2D pixel detect Edges Texture ep points image.

The 3D Pattern Extraction Algorithm computational efficiency, high accuracy in the localization of the edge points, easy implementation, and robustness against noise.

**Use Case**

As a continuation of the previous Use Case in Section 4.4.3, the user wants to extract the 3D pattern of Mr Riza's body and store the two generated 2D images in the Greek police files.

**3D Pattern Extraction Algorithm**

The stages for the 3D pattern extraction of Mr Riza's body are:

**Step 1:** The user opens the 3D model mesh scene, adjusts the camera to a position with a good angle of view for Mr Riza’s body, and selects the Mark Area to Extract 3D Patterns Tool.

![Figure 108: Step 1 of the '3D Pattern Extraction Algorithm'.](image-url)
**Step 2:** The user decides to create the 3D parallelogram using the Point Selection Mode and not the Parallelogram Editing Options. He/She observes that the Point Selection Mode is enabled and so presses the 'Left Alt' keyboard key, to enables the Inspection Mode to reposition the camera’s angle of view. After the successful camera reposition, the user presses the 'Left Alt' key, once more, to restore the previous Mode.

![Figure 109: Step 2 of the '3D Pattern Extraction Algorithm'.](image)

**Step 3:** The user finds the creation point of the 3D parallelogram and presses a mouse left-click. A 3D parallelogram with an inner plane will be created in the selected point with specific dimensions and with rotation the camera’s rotation.

![Figure 110: Step 3 of the '3D Pattern Extraction Algorithm'.](image)
Step 4: The user opens the Parallelogram Editing Options Menu with a right-click in a point of the 3D scene and observe that all buttons are enabled except the 'Add Selection Area' button. The 'Add Selection Area' button is disabled since the 3D parallelogram is already being created. The user searches and find the 'Resize Selection Area' button.

Figure 111: Step 4 of the '3D Pattern Extraction Algorithm'.

Step 5: The user presses the 'Resize Selection Area' button. The opened Menu closes and a Gizmo Transformation for resizing is enabled in the centre point of the parallelogram. The user sets the parallelogram to a desirable scale using mouse left-drags and keyboard keys.

Figure 112: Step 5 of the '3D Pattern Extraction Algorithm'.
**Step 6:** The user presses the ‘B’ keyboard key to enable the Relocation Mode and makes adjustments to the parallelogram location following similar steps as in the previous step.

![Figure 113: Step 6 of the '3D Pattern Extraction Algorithm'.](image)

**Step 7:** The user presses the 'N' keyboard key to enable the Rotation Mode and makes adjustments to the parallelogram rotation following similar steps as in steps 5 and 6.

![Figure 114: Step 7 of the '3D Pattern Extraction Algorithm'.](image)
**Step 8:** The user makes the final adjustments to the parallelogram rotation, resizing, and relocation following similar steps as in steps 5, 6, and 7. After the adjustments, the user presses the 'L' keyboard key to disable the enabled Mode and to enable the Inspection Mode.

![Figure 115: Step 8 of the '3D Pattern Extraction Algorithm'.](image)

**Step 9:** The user opens the Parallelogram Editing Options Menu and presses the 'Move Plane' button. Using the keyboard keys user set the inner plane of the parallelogram to the desired level in the z-axis, ranged in the 3D 'ParallelogramHeight'. After the adjustments, the user presses the 'L' keyboard key to disable the enabled Mode and to enable the Inspection Mode.

![Figure 116: Step 9 of the '3D Pattern Extraction Algorithm'.](image)
Step 10: User adjusts the Bottom and Upper Thresholds in the '3D Pattern Extraction Algorithm' Settings Options section, for better results of the 3D Pattern Extraction Algorithm, guided by the preview image, placed in the bottom right-oriented side of the system.

![Figure 117: Step 10 of the '3D Pattern Extraction Algorithm'.](image)

Step 11: The user opens the Parallelogram Editing Options Menu and presses the '3D Pattern Extraction' button. A 'Please Wait' message is displayed in the 3DMA until the system finishes the placement of the 3D green primitive spheres. After the completion of the placement, a pop-up window is displayed on the screen, informing the user of two created '.png' images in a folder inside the opened project file path. The user presses the 'Ok' button and sees that the pop-up window disappears. The user finds and checks the two created images (Depth Texture - Figure 119, Edges Texture - Figure 120).

![Figure 118: Step 11 of the '3D Pattern Extraction Algorithm'.](image)
Figure 119: The created Depth Texture image of Step 11 of the '3D Pattern Extraction Algorithm'.

Figure 120: The created Edges Texture image of Step 11 of the '3D Pattern Extraction Algorithm'.

Step 12: Finally, the user is pleased with the final result of the 3D extracted pattern of Mr Riza's body and the two '.png' images and so he/she saves the current status of the project changes.

Figure 121: Step 12 of the '3D Pattern Extraction Algorithm'.
4.4.5 3D Pattern Extraction Annotation Tool/Mode

Description

The 3D Pattern Extraction Annotation Tool offers the ability to edit the created Groups from the Mark Area to Extract 3D Patterns Tool. Three of the most basic properties of this Tool are the addition and subtraction of 3D green spheres primitives to a selected Group, as well as the commenting on these Groups and primitives.

Input

A 3D model in the form of a mesh of triangles is provided in which users can interact in order to make notes or modify existing ones in a Group. Additionally, the user clicks in GUI, mouse clicks and keys 'A', 'Q', 'W', 'E', 'S', 'D', 'Shift', 'Left Alt' from the keyboard are inputs provided by the user.

Output

As an output, this Tool provides Point collections of 3D p points represented as dark green 3D spheres primitives.

Visualization

The 3D Pattern Extraction Annotation Tool allows users to make further editing to the extracted Groups, that were created in the Mark Area to Extract 3D Patterns Tool. If no such Groups have been created this Tool is disabled by the system. When users select this Tool, the Inspection Mode is activated. Each Group’s primitive has Point Editing Options (Section 4.4.5) and are accessible from the currently selected point. Users can select a created Group by pressing a c left or right-click in one of the Group’s p primitives points. If a 3D green primitive is selected, the selected primitive change its color from green to blue, and all 3D spheres in the selected Group change their color from dark green to light green, indicating the selected Group. When a Group is selected the Inspection Mode is deactivated and the system enables the Point Selection Mode so that the users can use the Point Selection Algorithm from Section 4.4.2, in Methods. Users can deselected the selected p sphere primitive or exit the Eraser Mode (5) in Point Editing Options in Section 4.4.5) with double c left-clicking, in a random position of the screen space. Also, if 'Left Alt' is pressed the system disables the Point Selection Mode or the Eraser Mode and enables the Inspection Mode until the 'Left Alt' keyboard key is pressed again. If a 'Point Description' (2) in Point Editing
Options in Section 4.4.5) is applied to a \textbf{p} primitive, the primitive changes its color from green to yellow.

In a selected Group can be made additions using Point Annotations or Pen Group Annotations, as well as subtractions using the Eraser Mode. If additions and subtractions have been made in a Group and the user saves the new changes, these changes will have to resonate to the saved '.png' image Edges Texture as well.

\section*{Point Editing Options}

All 3D Pattern Extraction Annotations have editing options. For accessing these options, a green sphere \textbf{p} primitive must be selected with a \textbf{c} right-click. Its colour will change from green to blue, irrespectively of whether the selected sphere is in the active Group or not, and the Editing Options Menu will open.

These options are represented in the form of buttons in a circular Menu, have a Tooltip feature, and are as follows:

1. \textbf{Group Description}. Opens the Group Description Window (Figure 69) for the selected Group to add text or edit the existing one, and closes the Point Editing Options Menu. If a Group has a Group description and one of its primitives is selected, the Group Description Window will open.

2. \textbf{Point Description}. Opens the Point Description Window (Figure 68) for the selected point to add text or edit the existing one, and closes the Point Editing Options Menu. When the Point description is added and it’s not empty, the green selected primitive turns its colour from blue to yellow.

3. \textbf{Delete Point}. Deletes the selected blue primitive, and closes the Point Editing Options Menu.

4. \textbf{Delete Group}. Deletes the Group of the selected primitive, and closes the Point Editing Options Menu.

5. \textbf{Eraser (Eraser Mode)}. Enables the Eraser Mode and closes the Point Editing Options Menu. Eraser Mode is erasing the green primitives if the \textbf{c} mouse left-click is continuously pressed over green primitives, in the selected Group. When Eraser Mode is enabled, the Inspection Mode is deactivated by the system and the Point Selection Mode is enabled.

6. \textbf{Close Menu}. It closes the Point Editing Options Menu.
Methods

Point Annotation

Point Annotation is one closed p point, using the Point Selection Algorithm in Section 4.4.2, in Methods. This p point is selected through the Point Selection Mode, using mouse left-click or the presses of keyboard key 'A'. The closed p point is represented as one green 3D sphere primitive.

Pen Group Annotation

Pen Group Annotation uses the c point indicated by the mouse in combination with the 'A' pressed keyboard key. While key 'A' is pressed, Point Selection Algorithm (Section 4.4.2) is activated, through the Point Selection Mode, forming p points in a row. This makes the impression of freestyle pen lines and contours. These p_i points are represented as green 3D spheres primitives.

Use Case

As a continuation of the previous Use Case in Section 4.4.4, the user wishes to delete some of the 3D green primitives in the Group of the 3D extracted pattern of Mr Riza's body, add a small Pen Group Annotation in the waist of Mr Riza, and make some Point Annotations at his choice.
Point Annotations and Pen Group Annotation

The stages for adding and subtracting 3D green primitives in the 3D extracted pattern Group of Mr Riza is:

**Step 1:** The user selects the 3D Pattern Extraction Annotation Tool and adjusts the camera to a position with a good angle of view for the Group of Mr Riza's body.

![Figure 123: Step 1 of the 'PointAnnotations and Pen Group Annotation'](image)

**Step 2:** The user selects with mouse left-click a green sphere primitive from the Group of Mr Riza's body. The primitive will change its colour from green to blue and all Group primitives will change their colours from dark green to light green respectively. The Point Selection Mode will be activated.

![Figure 124: Step 2 of the 'PointAnnotations and Pen Group Annotation'](image)
**Step 3:** The user right-clicks over the blue primitive and sees to open the Point Editing Options Menu. The user finds the 'Eraser' button.

![Figure 125: Step 3 of the 'Point Annotations and Pen Group Annotation'.](image)

**Step 4:** The user presses the 'Eraser' button. The Point Editing Options Menu closes, and the mouse icon will change from arrow to eraser, indicating that the Eraser Mode is now activated.

![Figure 126: Step 4 of the 'Point Annotations and Pen Group Annotation'.](image)
**Step 5:** The user deletes the desired 3D light green primitives and double left-clicks to a random point in the screen space to disable the Eraser Mode. All the Group primitives will change their colour from light green to dark green.

![Figure 127: Step 5 of the 'Point Annotations and Pen Group Annotation'.](image)

**Step 6:** The user presses, once again, a green 3D sphere with a mouse left-click and change its colour from green to blue. All the 3D spheres in that Group changes their colour from green to light green activating the Point Selection Mode. The user uses the 'A' keyboard key to annotate a Pen Group Annotation over the body’s waist to complete the missing line.

![Figure 128: Step 6 of the 'Point Annotations and Pen Group Annotation'.](image)
**Step 7**: Also, the user uses the Point Selection Mode to annotate some more 3D primitives of his choice using mouse left-clicks and key 'A' from the keyboard.

![Figure 129](image1.png)  
*Figure 129: Step 7 of the 'Point Annotations and Pen Group Annotation'.*

**Step 8**: The user saves the new changes and observes the new changes applied in the Edges Texture '.png' saved image of the Mr Riza Group.

![Figure 130](image2.png)  
*Figure 130: Step 8 of the 'Point Annotations and Pen Group Annotation'.*
4.5 3DMA Storage File System

4.5.1 Description

A project is defined as a single file, with a '.3dma' file type. To work properly, it must be in the same folder with a file '.obj'. This file is the 3D model mesh that the system loads for annotation.

4.5.2 *.3dma File Format

The system defines as a project a particular '.3dma' file. This file contains five main sections. The first has to do with the path of the '.obj' file, and consequently the path of the specific project. The second deals with whether the parallelogram in the 'Mark Area to Extract 3D Patterns' has been created or not. If it has, all necessary data are stored in the '.3dma' file so that it can be recovered again. The third section contains all the information regarding the annotations of the first Tool, the Simple Annotation (Section 4.4.2). The fourth and fifth concern all the information regarding the annotations for the 3D Pattern Extraction Annotation Tool (Section 4.4.5) and the Path Finder Annotation Tool (Section 4.4.3) respectively.

//Json.NET format example
{
    // -----------------------------Section 1
    "iiidModelPath": "File Path for the .obj file", //string

    // -----------------------------Section 2
    "parallelogramExistence": "YES/NO", //string
    "parallelogramPosition": {
        "x": 0.0, //float Number
        "y": 0.0, //float Number
        "z": 0.0 //float Number
    },
    "parallelogramRotation": {
        "x": 0.0, //float Number
        "y": 0.0, //float Number
        "z": 0.0 //float Number
    },
    "parallelogramScale": {
        "x": 0.0, //float Number
        "y": 0.0, //float Number
        "z": 0.0 //float Number
    }
}
},
"planePosition": {
    "x": 0.0, //float Number
    "y": 0.0, //float Number
    "z": 0.0 //float Number
},

// -------------------------------------------------------
Section 3
"annotations": [
    {"GroupInfo": [
        {
            "hitPoint": {
                "x": 0.0, //float Number
                "y": 0.0, //float Number
                "z": 0.0 //float Number
            },
            "textInfoPerSphere": "Text" //string
        },
        {
            "hitPoint": {
                "x": 0.0, //float Number
                "y": 0.0, //float Number
                "z": 0.0 //float Number
            },
            "textInfoPerSphere": "Text" //string
        }
    ],
    "textInfoPerGroup": "Text" //string
}],

// -------------------------------------------------------
Section 4
"annotationsDetectEdges": [
    {"GroupInfo": [
        {
            "hitPoint": {
                "x": 0.0, //float Number
                "y": 0.0, //float Number
                "z": 0.0 //float Number
            },
            "textInfoPerSphere": "Text" //string
        },
        {
            "hitPoint": {
                "x": 0.0, //float Number
                "y": 0.0, //float Number
            }
        }
    ]}
4.5.3  *.obj File

"OBJ (or .OBJ) is a geometry definition file format that has been first developed by Wavefront Technologies for its Advanced Visualizer animation package. The file format is accessible and has been adopted by other 3D graphics application vendors.
The OBJ file format is a simple data format that represents 3D geometry alone — namely, the position of each vertex, the UV position of each texture coordinate vertex, vertex normals, the faces that make each Group defined as a list of vertices, and texture vertices. Vertices are stored in a counter-clockwise order by default, making explicit declaration of face normals unnecessary. OBJ coordinates have no units, but OBJ files can contain scale information in a human-readable comment line" [44].
Chapter 5: Evaluation

5.1 Evaluation Methods

There are several inspection techniques available for expert-based evaluation. For the evaluation of the 3DMA system, we worked with the most commonly used: the cognitive walkthrough and the heuristics evaluation.

5.1.1 Cognitive Walkthrough Evaluation

The Cognitive walkthrough [45] technique evaluates the overall user interface of a system and focuses on how a system is perceived by users the first time they use it without any prior formal training. The goal of the evaluation was to identify any potential issues regarding the concept, missing features, and usability errors through comments from the experts, before planning a large-scale user-based evaluation.

Specifically, in cognitive walkthroughs, the expert has the following questions in mind while examining the application or system:

- Does the user know what to do? Is it the correct action?
- Will the user notice that the correct action is available? Is the action visible? Will users recognize it?
- Will the user associate the correct action with the effect to be achieved? The action may be visible, but will the user understand it?
- If the correct action is performed, will the user see that progress is being made toward the solution of the task? Is there system feedback to inform the user of progress? Will they see it? Will they understand it?

5.1.2 Heuristic Evaluation

A Heuristic Evaluation is a usability inspection method for computer software that helps to identify usability problems in the user interface (UI) design [46] [47].
Specifically, it involves evaluators that examine the interface and judge its compliance with recognized usability principles, the "heuristics". Heuristics evaluation is a commonly used method in the HCI field especially in early design iterations because it is effective, quick to produce results, and does not require many resources. In addition, it can, in principle, take into account a wider range of users and tasks than user-based evaluation. It assesses if the application or system satisfies user requirements. During the heuristic evaluation, the inspection is ideally conducted by HCI usability experts who base their judgment on prior experiences and knowledge of common human factors and ergonomics guidelines, principles, and standards. Heuristics evaluations, as well as cognitive walkthroughs, can also be performed by technology domain experts with experience in common design practices in their field of expertise.

5.2 Process

A Cognitive walkthrough inspection technique evaluation was performed once per month with the help of two or three HCI usability and interaction experts and/or a technology 3D domain expert for the improvement of the implemented 3DMA system so far. Then a brainstorming session occurred about the final changes and modifications that needed to be done, for the best usability of the implemented system. These changes were properly fixed and correctly implemented until the next Cognitive Walkthrough Evaluation session.

For the final version of the system, a heuristic evaluation experiment of the 3DMA system was conducted with the participation of three (3) User Experience (UI/UX) experts with prior experience in designing systems and two (2) technical domain experts in 3D environments, also with great experience in evaluations on interaction systems. The evaluation process was conducted at the Human-Computer Interaction Laboratory (HCI) of the Institute of Computer Science of the Foundation for Research and Technology - Hellas (ICS-FORTH). During the evaluation, a conductor was present to help the UI/UX experts during the experiment. Users were given a sequence of tasks, one by one, and after each task, the conductor asked a sequence of questions. The questions were related to the difficulties of the users for the execution of the tasks, for the better understanding of the suggested changes that will have to be made according to the users, and the specification of the usability problems. The conductor was responsible for keeping notes for each task containing any comments or suggestions from the experts and recorded the answers for each question.
5.2.1 Heuristic Evaluation Findings

The heuristic evaluation of the 3DMA system revealed twenty-seven (27) usability issues, as given by the five (5) expert evaluators. Table 2 below presents the extracted issues along with their severity score [48] provided by the experts.

Severity grading Scores (decimal scores are allowed):

0 = Not a usability problem at all
1 = Aesthetic problem only
2 = Minor usability problem
3 = Major usability problem
4 = Usability catastrophe

Status:

 getSupportActionBar(): Resolved

Future Work

Table 4: List of reported issues of the Heuristic evaluation

<table>
<thead>
<tr>
<th>Usability Issues</th>
<th>Average Severity grading scores</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General UI comments</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>When a 3D object is loaded, the camera should be zoomed out to the level where the entire 3D model fits in the boundaries of the screen.</td>
<td>2.2</td>
<td>✔️</td>
</tr>
<tr>
<td>X, Y, Z boundaries should be specified in the 3D scene so that the 3D model does not get outside the screen view. Bringing it back is too difficult for a novice user.</td>
<td>2.5</td>
<td>✔️</td>
</tr>
<tr>
<td>There is no functionality to re-center a 3D model in the screen, which is much needed when the user cannot bring it back into the viewing screen.</td>
<td>2.5</td>
<td>✓</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>The labels, texts, and button names of the entire 3DMA system should be less computer oriented and more user-friendly.</td>
<td>1.9</td>
<td>✓</td>
</tr>
<tr>
<td>The point sub-Menu (circular Menu around each point) should open with a more direct user action, e.g. right-click on point, double-clicking, etc., rather than having to select the point (left-click) first and then right-click to open it.</td>
<td>2</td>
<td>✓</td>
</tr>
<tr>
<td>The sphere should have some level of transparency so it doesn’t hide what it is behind it.</td>
<td>1.9</td>
<td>🔴</td>
</tr>
<tr>
<td>The 'FreeLook' camera option is too complicated for a novice user. Make the 'Trackball' camera the default option instead.</td>
<td>2.4</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Simple point annotation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clicking on a point should show both the Menu and the Point Description at the same time.</td>
<td>2.1</td>
<td>🔴</td>
</tr>
<tr>
<td>The action to close a Group is not obvious to the user. The user expects to be able to click on the initial point again to close the group, (like in common photo editing software).</td>
<td>2.7</td>
<td>✓</td>
</tr>
<tr>
<td>The Group Description should be opened by clicking on the line of the Group rather than by clicking on one of its points.</td>
<td>2.2</td>
<td>🔴</td>
</tr>
<tr>
<td>Open a Group Description when the user chooses and not automatically when the user presses a 3D sphere.</td>
<td>1.9</td>
<td>🔴</td>
</tr>
<tr>
<td>When the user selects to move a point, there is no hint (tooltip) as to what action needs to be done to accomplish that, i.e. user must click on the new desired position.</td>
<td>2.3</td>
<td>✓</td>
</tr>
<tr>
<td>Task</td>
<td>Issue</td>
<td>Severity</td>
</tr>
<tr>
<td>------</td>
<td>-------</td>
<td>----------</td>
</tr>
<tr>
<td>Clear a text annotation.</td>
<td>There is no quick way to Clear a text annotation. The user must select all text from the window and click delete from the keyboard.</td>
<td>2.2</td>
</tr>
<tr>
<td>Text entered in the annotation box</td>
<td>The text entered in the annotation box should be vertically aligned to the top.</td>
<td>1.4</td>
</tr>
<tr>
<td>Description box carets</td>
<td>The caret in the Description box is not visible. The user is not sure if he/she can write in the box.</td>
<td>1.6</td>
</tr>
<tr>
<td>Mark area to detect edges (placing 3D plane over an object in the scene)</td>
<td>The 'Mark an area to detect edges' function should be initialized just like the other Tools, i.e. upon Tool selection, the cursor changes to the '+' icon, and the user clicks on the 3D model to mark the area. Currently, the user has to right-click on the model to activate the Menu and select the only available option 'select area'.</td>
<td>2.5</td>
</tr>
<tr>
<td>Plan manipulation for novice users</td>
<td>For a novice user manipulating the plane to mark an area can be overwhelming. The green plane should be placed automatically on the model upon clicking on it, at a manageable scale.</td>
<td>2.9</td>
</tr>
<tr>
<td>Plane relocation keys</td>
<td>The keys to relocate a plane, W and S, are backward. The 'W' should be for going up and the 'S' for going down and not the other way around.</td>
<td>1.9</td>
</tr>
<tr>
<td>Plane placement for best results</td>
<td>It is not obvious to the user how to place the plane in order to get the best results. Instructions and quick tips should be provided.</td>
<td>2.8</td>
</tr>
<tr>
<td>Step order for pattern extraction</td>
<td>User is not aware of the order of the steps he/she needs to do to extract a pattern from a model, (i.e.: first mark area, then detect edges and find produced 2D images). Instructions, tooltips, and/or button labels are needed.</td>
<td>2.9</td>
</tr>
<tr>
<td>Detect edges output</td>
<td>The output of the detect edges actions, i.e. the two 2D images that are automatically being produced and saved in a folder, is not obvious to the user. A confirmation message that the images are created is needed.</td>
<td>2.7</td>
</tr>
</tbody>
</table>
Twenty-one (21) usability issues were found, with the average score of all the issue scores is about two point three \( (47.5/21 = 2.261 \cong 2.3) \). Sixteen (16) of them have been already resolved and five (5) are for future work.

The severity scores results were counted as:

- **Not a usability problem at all**: Zero (0) usability issues (Rating: 0 - 0.5)
- **Aesthetic problem only**: One (1) usability issue (Rating: 0.6 - 1.5)
- **Minor usability problem**: Fifteen (15) usability issues (Rating: 1.6 - 2.5)
- **Major usability problem**: Five (5) usability issues (Rating: 2.6 - 3.5)
- **Usability catastrophe**: Zero (0) usability issues (Rating: 3.6 - 4)

The severity scores result after the resolved of some usability issues were counted as:

- **Not a usability problem at all**: Zero (0) usability issues (Rating: 0 - 0.5)
- **Aesthetic problem only**: Zero (0) usability issue (Rating: 0.6 - 1.5)
- **Minor usability problem**: Five (5) usability issues (Rating: 1.6 - 2.5)
- **Major usability problem**: Zero (0) usability issues (Rating: 2.6 - 3.5)
- **Usability catastrophe**: Zero (0) usability issues (Rating: 3.6 - 4)

Overall, the five (5) user experts were able to interact with the tool's components after minimum training and explanation. All the users expressed positive comments about the potential of the system and the more expert users envisioned several additional use cases where it would be useful.

Most of the reported findings were minor issues that concerned general interface inconsistencies and aesthetics, whereas the major issues observed concerned the Inspection Tool, i.e. the user interaction with the 3D model via the two cameras, and the 'Mark Area to extract 3D patterns' tool.

In regards to the Inspection Tool and the movement of the camera in relation to the model the experts gave valuable suggestions to further enhance the user experience of interacting with the 3D model, such as:

- Applying boundaries to space where the camera can move in relation to the 3D model so that the latter is always visible in the working space.

- Adding functionality to re-centre the camera in the space.
• Making the Trackball camera the default camera of the system because it is the easiest to use.

Whereas, the two experts with experience in 3D environments appreciated the freedom and flexibility the FreeLook camera allows, but also suggested that a combination of the two cameras would be the optimal solution, i.e. use of the mouse for moving the camera left, right, up, down and zooming and a combination of keys for rotation. The above suggestions are included in the future work described in the next paragraph.

In regards to the Mark area to extract 3D patterns Tool, the experts expressed concern that it is not obvious to the user how the 3D plane should be placed over the area of interest to extract the best results. Furthermore, the HCI experts showed more difficulty to resize and move the plane from its original placement which covered the entire model. To this end, adjustments were already made to the functionality of the tool to make it easier in its use. Specifically, the user can now click on the area of interest and the system automatically inserts the plane over that area at a smaller size for easier manipulation.
Chapter 6: Conclusion and Future Work

This Master Thesis was conducted in the context of the Mingei H2020 EU project which supports the vision of representation and preservation of Heritage Crafts [49]. The main goal of this thesis was to design and develop the 3D Model Annotator (3DMA), a user-friendly annotation editor for the spatial markup of 3D models. The 3DMA introduces a holistic approach to the process of creating and editing 3D Point or Group annotations, represented as coloured 3D spheres, on a 3D model mesh. Initially, it includes the possibility of creating a project, its storage as well as its opening for further processing. It consists of five (5) Tools and are analysed below.

The first (1st) Tool (Section 4.4.1) deals with the ability to inspect the 3D model mesh in two different ways. The second (2nd) Tool (Section 4.4.2) allows the user to repeatedly select p points in a meaningful way, connected with a three-dimensional straight line per two 3D p points. These p points are represented as red 3D spheres primitives. In this Tool, users can create an annotation consisting of one 3D p point (Point Annotation) or at least two 3D p points (Group Annotation/Pen Group Annotation). The third (3rd) Tool (Section 4.4.3) relies on the algorithm of the second Tool but differs in the connection between the annotations. The connections are performed using three-dimension Geodesic lines per two 3D p points and the system allows only Group Annotations (two and more 3D p points). The p points in this Tool are represented as purple 3D spheres primitives.

In the fourth (4th) Tool (Section 4.4.4), users can extract 3D patterns from a 3D model mesh using a parallelogram with an inner plane and the 3D Pattern Extraction Algorithm (Section 4.4.4, in Method). The 3D Pattern Extraction Algorithm features computational efficiency, high accuracy in the localization of the edge points, easy implementation, and robustness against noise. In the fourth (4th) Tool take place the placement of the parallelogram in a desirable position on the 3D model mesh, and the 3D pattern extractions. The 3D extracted patterns are usually consisted of multiple p points and are represented as green 3D spheres primitives. Additionally, for each 3D pattern extraction, the system produces two '.png' images for the 3D extracted pattern. The first image represents the 3D extracted pattern to a 2D Depth/RGB_Intensity Texture image and the second to a 2D pixel detect Edges Texture image. In the fifth (5th) Tool (Section 4.4.5), the created 3D patterns can be modified and edited appropriately.

All the p points (represented as sphere primitives) have editing options, depending on the tool category to which they belong, and in each 3D Point or Group, annotation can
be added a text description. Finally, the 3DMA system provides instructions of use for each of the five Tools, and Settings options depending on the enabled Tool and the active Camera. The 3DMA is already in use by researchers, academics, and curators in the Human-Computer Interaction Laboratory of the Institute of Computer Science, at Foundation for Research and Technology - Hellas (ICS - FORTH). Planned future work includes tackling all unaddressed issues discovered during the real-time use of the 3DMA system by end-users as well as the findings of the final Heuristic Evaluation. A detailed plan for future work is described below:

I. All five unsolved usability issues from the Heuristic evaluation.

II. A combination of the FreeLook and the Trackball would be the best mode of interaction. I.e., the user can move inside the scene with the mouse and use the keyboard keys to go tilt, rotate, etc.

III. Documentation for the overall whole 3DMA system.

IV. Add a semantic segmentation feature in the Path Finder Annotation Tool. Users could change the texture inside a closed Group with a colour of their choice.

V. Insert a feature in the Path Finder Annotation Tool, so that users can extract the selected area inside a Group and save it as a new 3D model mesh (separate .obj file).

VI. Add as a general feature a list of all the 3D annotation Groups for each Tool with a label name, and redirection ability of the camera to the user-selected annotation.

VII. Log in feature and specify a username for each Point or Group Description.

VIII. Possibility of multiple text descriptions for each Point or Group Annotation.

IX. Provide location-specific context and information and enhance support for the presentation of material in various technical contexts e.g. AR, VR, and MR.
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