

AN INTERDISCIPLINARY LITERATURE SURVEY FOR DEGREES OF FREEDOM OF SPATIAL DESIGN

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ABSTRACT:

The reproduction of pictorial scenes in a digital space is a reconstructive practice that has become well established in the digital humanities. In this particular case, the applicative example is the reconstruction of the depicted sceneries by Caspar David Friedrich. This study aims to provide the opportunity to investigate stylistic aspects and sizing inconsistencies that are peculiar to the painter. The transition from 2D pictorial space to 3D reconstruction requires a separate methodological analysis concerning the criteria and categories through which this transition has to be investigated. As both of these types of representation contain common characteristics, the 'translation' between the two methodologies has to be delivered through shared categories. Grasping categories with which this process has to be explored requires a definition of Literature Survey that includes bibliographical sources related to 2D and 3D representation and their visualisation and perception. The analysis of the literature is based on a qualitative content analysis methodology. The process leads us to identify interdisciplinary categories defined through an inductive analysis of the sources and a hierarchical structure of main categories (Degrees of Freedom) and sub-categories.

KEY WORDS: Digital Humanities, Literature Survey, Degrees of Freedom, Caspar David Friedrich, Qualitative Content Analysis, Mayring.

1. INTRODUCTION

Looking at art history research, it is vital to consider how the use of digital technologies has led to the creation of a new way of conceiving the discipline, if we consider how the use of such methodologies has helped and enabled innovative possibilities of interacting with works of art. Therefore artworks and paintings have been repositioned as conjunctions between very disparate disciplines, that can be used to analyze, enhance and reconstruct the perception of the pictorial composition of Caspar David Friedrich.

In particular the 3D reconstruction of 2D representations in a digital space is a topic that the scholarship has repeatedly highlighted and studied to deliver the three-dimensional characterization of paintings through 3D modeling techniques.

What needs to be defined are the categories through which the reconstruction of the depiction can be analyzed, communicated and perceived.

Consequently, this study aims to:

- Understand according to which categories 3D modelling and 2D representations are able to communicate in the shift from one form of representation to the other.
- Understand how those Degrees of Freedom are conceived by different subjects and analyze the several standpoints about the same Degrees of Freedom.
- Identify, as an applicative example, in an interdisciplinary environment, which categories can be used to investigate the potential of reconstructing the peculiarities of Caspar David Friedrich's paintings in three-dimensional digital space.

2. STATE OF THE ART

2.1 3D digital reconstruction of 2D representations

The relationship between digital technologies and art history does not only concern the aspect of the cataloguing and systematizing of iconographic material. Although if we focus on

the study of literature on this issue, we find many studies on the employment of digital methodologies exploited for the development of databases with the aim of systematizing and retrieving useful representations for scholars in several scientific fields (Lang and Ommer, 2018). On the other hand, not many projects consider how digital technologies can be deployed for the definition of methods concerning the analysis of the perception of artworks not only as two-dimensional compositions but also as three-dimensional spatial environments (Lourakis, Alongi, Delouis, Lippi and Spadoni, 2007; Criminisi, Kemp and Zisserman, 2002).

2.2 3D reconstruction as an analytical tool.

In the methodological context of 3D modeling, it is useful to define the handling of a two-dimensional representation (such as a painting) through categories that are appropriate for 3D modeling as an analytical tool. For this purpose, it is essential to understand how the reconstruction of a depiction can be adapted to a tool such as 3D modeling by analyzing its peculiarities and limitations. This type of process in itself creates a conjunction between the investigated subject and the analytical methodology between the examined painting and the 3D modeling tool.

2.3 Degrees of Freedom

The aforementioned categories will henceforth be called "Degrees of Freedom". It is a concept borrowed from disciplines that are far from art history, such as statistical and mathematical sciences. As far as those subjects are concerned, "Degrees of Freedom" are defined as "the number of independent parameters that are needed to specify the configuration of a system" (Daintith and Rennie, 2005, p. 60). In order to define these Degrees of Freedom in our interdisciplinary research field, a Literature Survey within the disciplines concerning 2D representation methods and 3D reconstruction has been conducted.

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2.4 Degrees of Freedom and Caspar David Friedrich

The subject of this study is the analysis of the depiction by Caspar David Friedrich, due to the fact that some of the aesthetic features of his composition can be easily analyzed through 3D modelling techniques. In particular, the German painter distinguishes himself by his elaboration and reconstruction of pictorial space aimed at defining a scene in which inconsistencies in the volumetric setting creates disorientation in the observer. (Grave, 2012)

An example, that defines these peculiarities as Degrees of Freedom that influenced Friedrich's work, is the scaling and sizing of the instances of representation considering the perspectival structure created by the painter. This representational inconsistency, for instance in the painting *The Sea of Ice*, is precisely described by Johannes Grave in his monography on Friedrich. Grave mentions the relationship between the size of the objects in the representation and the perspective definition of the depiction as the painter's denial of the aesthetic concept of the sublime in his work (Grave, 2012). Indeed, the presence of elements that disorient the observer, forcing them to a loss of spatial awareness, leads to a break between the painted scene and its observer, a materialized caesura on the pictorial surface.

Recognizing which aspects and formal categories lead to this detachment between the observer and the work of art and which Degrees of Freedom identify formal inconsistencies with the represented scene would reconcile the volumetric composition of the painter's representation in digital space.

3. METHODOLOGY

3.1 Mayring's qualitative content analysis method

In order to be considered scientifically reliable, the literature analysis must be handled with a structured and reproducible method based on a well-defined and streamlined methodology. The aforementioned methodology is Mayring's qualitative content analysis method, which, through a critical analysis of the literature, lets us define the categories through the detailed analysis of an interdisciplinary bunch of sources. Through the different steps of Mayring's methodology, certain categories regarding a portion of the entire bunch of articles will be detected and then they will be questioned and analyzed within the remaining portion of the articles (Mayring, 2000).

3.2 Application of Mayring's method to an Interdisciplinary Literature Survey

Mayring's method for qualitative research applied to the field of Digital Art History and 3D reconstruction of two-dimensional representations has been employed with a systematic and hierarchical approach. In order to do so, the principles of Mayring's methodology have been preserved as far as the quantitative approach and the inductive definition of categories were concerned. For this reason, a hierarchical system of categories was defined so that it would lead to a progressive definition of the Degrees of Freedom.

The core process of the literature survey is the process of coding. A code has been defined by Saldana in his *Coding Manual for Qualitative Researchers* as "a word, or a short phrase that symbolically assigns a summative salient essence capturing and/or evocative attribute for a portion of a language-based or visual data"(Saldana, 2009, p. 3). During the coding phase, the textual sources are analyzed by dividing them into paragraphs and applying a code to each of the identified

paragraphs. From a practical point of view, considering all the 60 examined sources, the first coding operation was carried out on all the reviewed literature. Thereby, an immense number of codes with a very specific focus on the subject matter are obtained. These codes, closely linked to the discipline of the material they are derived from, are exceptionally hard to organize and to use as key categories for the analysis of the shift from 2D representation to 3D reconstruction. For this reason, the highly specific categories are then grouped together within overarching categories so that they can be systematized and clustered more effectively (Figure 1). With this rigid and hierarchical coding mode, it is possible, by grouping the categories again, to ultimately obtain the Degrees of Freedom. These Degrees of Freedom, gained through this hierarchical and inductive method, are interdisciplinary. This is due to the fact that the specific categories subsumed within them belong to articles related to different disciplines. In Figure 1, the code headings for different paragraphs of the examined sources are highlighted in yellow. Blue codes indicate the subject categories that encompass the codes for the different paragraphs. Green codes describe the names of articles or chapters concerning the publication. In purple are the disciplines related to the different topics. Through this method of analyzing the literature, a hierarchical code system has been established, which allows to move from the general to the particular aspect of the subject.

☐ Digital Art History	0
☐ Is there a digital art history	18
☐ Visual Analysis of Chapbooks Printed in Scotland	15
☐ Beyond the Scanned Image: A Needs Assessment of Scholarly Use	32
☐ Developing a Qualitative Coding Analysis of Visual Artwork for	20
☐ Leonardo, Morelli, and the Computational Mirror	60
☐ Forgotten Genealogies	16
☐ Attesting similarity: Supporting the organization and study of	0
☐ DT can help AH in their job but not substitute them	3
☐ CVG Visual Interface: Database and Image Retrieval	0
☐ Results of Image Retrieval: An Analysis	0
☐ Analysis of differences between results: key for research	1
☐ The result of the research through CVG interface	3
☐ How CVG Interface retrieves images	0
☐ The algorithm detects images according to similarity assessment	1
☐ Functioning of the CVG interface	1
☐ Visual Interface based on Visual similarity	1
☐ Codex Manesse: An example of visual query image retrieval	0
☐ Similarity: original and copied	1
☐ Similarity: Gestures and objects	5
☐ The study of the Codex Manesse	1
☐ Analogical work of AH. How Could it be helped?	3
☐ Warburg's Atlas an analogical artworks classification	3
☐ Image Databases	1
☐ Similarity as concept	0
☐ What is conceived for similarity? Content and representation	1
☐ AH and Digital Technologies	6

Figure 1. Coding tree – Hierarchical structure of the detected codes.

Once these Degrees of Freedom had been defined for 70% of the analyzed sources (as the sources belong to different disciplines the percentage of examined sources for the initial inductive phase of Mayring's methodology was raised), these categories were verified within the remaining 30% of the sources, trying to establish whether these categories could also be considered reliable for the rest of the sources. Once these categories have been deductively verified within the entire literature, they can be deemed reliable for the investigated set of sources.

The process of testing and identifying Degrees of Freedom requires the qualitative researcher to have a level of abstraction and comprehension of the literature that enables the definition of categories embracing the specific themes belonging to the various disciplines. In that, the use of specific software for

qualitative research and analysis of heterogeneous materials such as MAXQDA is particularly useful. This software enables both the management and operational issues of an Interdisciplinary Literature Survey, considering the vast amount of material and data to handle. The software also makes it easy to manage the process of acquiring results and managing data from the survey. Through the software, it was possible to identify Degrees of Freedom (in black in Figure 2) by grouping subject-specific codes creating interdisciplinary and inclusive categories of different subjects as shown in Figure 2.

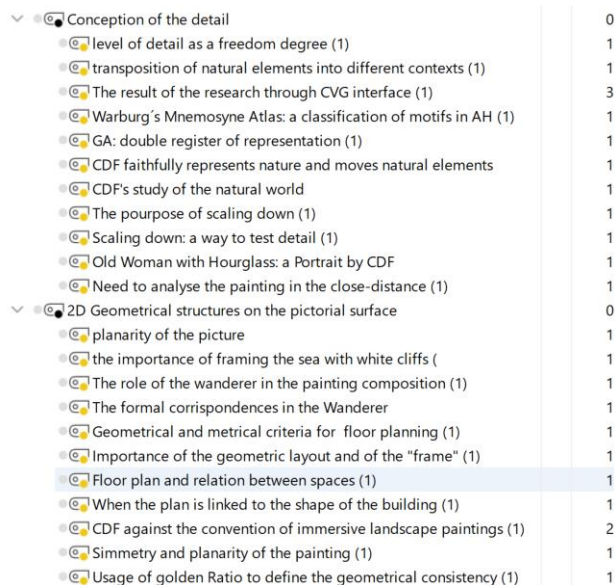


Figure 2. Coding tree – Degrees of Freedom and sub-codes

3.3 Data Collection

The structure of this Literature Survey for Degrees of Freedom research is defined through the collection of bibliographic materials that are heterogeneous both in type and subject matter. In the first part of the investigation, which will be presented here, the set of materials considered contains around 60 scientific articles, publications and monographies comprising heterogeneous subjects and contents that find common ground in two- and three-dimensional communication and representation. About half of the examined literature was retrieved from the Google Scholar and Research Gate databases. The remaining textual sources were collected from databases of specific publishers (Taylor & Francis), research institutions (Getty.edu), online libraries of universities (Uni-Heidelberg) or other scientific databases (Science Direct). Numerous different search terms were employed throughout these databases. The main ones are “3D modelling”, “3D reconstruction”, “3D modelling design”, “urban design aesthetics”, “architectural design”, “Degrees of Freedom perception”, “visual perception”, “gestalt psychology”, “Degrees of Freedom space”, “3D reconstruction of paintings”, “six degrees geometric modeling” and others.

3.4 Data Analysis

The 60 sources were first analyzed using a systematic reading of the abstract in order to understand whether these sources could contribute to the definition of Degrees of Freedom. After this analysis, five articles were removed due to not only the abstract but also the keywords associated with these articles (Table 1). After reading the remaining 55 articles in full, a further 14 were

removed as the contents within these sources were not deemed to be related to the search for categories that had a correlation with the 3D reconstruction of 2D representations (Table 2). The remaining 41 sources were analyzed through the Qualitative Content Analysis methodology.

Sources	Number of sources	%
Evaluated Sources	55	91,7%
Rejected Sources	5	8,3%
Total	60	100%

Table 1. Results of the preliminary Analysis of the Abstracts

Sources	Number of sources	%
Evaluated Sources	41	68,3%
Rejected Sources	19	31,7%
Total	60	100%

Table 2. Evaluated Sources after preliminary overall assessment

3.5 Topics

The topics covered and the number of articles per discipline are carefully balanced in order to keep the Literature Survey process as multidisciplinary as possible. The 41 articles were analyzed have also been clustered as to their topics in order to be able to understand the relevance of each discipline within the Literature Survey.

The examined materials are related to the topics that are described in the words cloud of the Figure 3.

Single-view reconstruction



Figure 3. Examined Topics

3.6 Keywords analysis

One of the most captivating aspects of the study concerns the difference between the various materials analyzed and how they can be compared as they all deal with the topic of representation, its visualisation and fruition. This leads, although the materials may be heterogeneous, to an overlap between the main topics of the different sources. The study of keywords is valuable to understand which specific themes are the most frequent within the analyzed set of sources. In the case of the proposed Literature Survey, the keyword study defines which specific topics were tackled in the selected set of sources. This type of study helps to emphasise, to the person conducting the study as well as to the person whose aim it is to evaluate it, which topics have been most frequently encountered. It, therefore, connects the identified Degrees of Freedom to specific technical topics discussed in the examined data. The first step of this analysis is related to the qualitative literature research. In fact, for many of the examined articles, it

was not possible to explicitly identify keywords given in the appropriate section of the publication. For this reason, it was necessary to proceed with the definition of keywords related to the source by cross-referencing the topics dealt with in the publication with the findings obtained within the qualitative analysis using Mayring's method.

Among the examined articles, 54% had the keywords explicitly mentioned in the article. In the remaining 46% for which the keywords were not specified, we used the aforementioned method.

Keywords source	Number of sources	%
Specified keywords in the source	22	54%
Deduced keywords from the content	19	46%
Total	41	100%

Table 3. Keywords specified in the sources and deduced through qualitative analysis.

The keywords identified are 123 in the different publications and Table 4 describes the frequency with which these describe the content of the different sources.¹

Keywords	Number of repetitions	%
"3D Modeling"	5	2,56%
"Art Architectural History"	3	1,54%
"Digital Humanities"	6	3,08%
"Digital Cultural Heritage"	4	2,05%
"Architecture"	5	2,56%
"Art"	3	1,54%
"Single View Reconstruction"	7	3,59%

Table 4. Most mentioned keywords

The table shows the keywords that were mentioned at least three times in the several articles. From the table, it can be seen that the search for sources focused on one of the topics closest to the main area of the shift between two-dimensional and three-dimensional representations. This is why "Single-view reconstruction" appears as the most frequently occurring keyword in the examined articles. Likewise, the transition from pictorial representation to 3D modelling comes into the foreground ("Digital Humanities", "3D Reconstruction") since through the study of the articles relating to these terms, it is possible to define the Degrees of Freedom relating to the different representational methods in both Digital Humanities and 3D modelling.

These keywords were further analyzed and clustered to understand their typology and their field of research. These studies and categorizations pursue the objective of learning how Degrees of Freedom are composed and which disciplines have contributed to the definition of the identified categories in this literature survey.

1. Some of the mentioned keyword have been employed to retrieve those articles through several source browsers. Some examples of keywords that have been used as research terms are: "3D Modeling", "3D Reconstruction", "3D Reconstruction paintings", "Creating models from images", "design process", "Design Degrees of Freedom" and others.

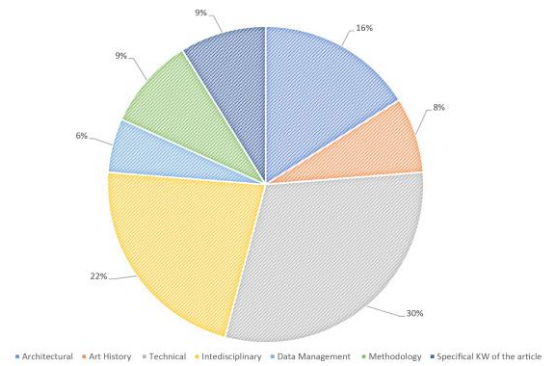


Figure 4. Typology of keywords.

The sorting of the 123 keywords by typology is fundamental to comprehending how the established categories are made up through this methodology. In particular, some general clusters were defined. They can be described as follows:

- **Architectural keywords:** KW related to architectural design, 3D reconstruction of new design and architectural heritage, architectural survey etc. (e.g. "Architecture", "Architectural survey")
- **Art historical keywords:** KW related to Romantic Art, Caspar David Friedrich, Interpretation of art, Digital Art History etc. (e.g. "Art", "Paintings")
- **Technical keywords:** KW related to technical aspects of the specific context of the article's discipline. Those aspects are related to technical concepts that are very specific for the article and they don't belong to the two aforementioned categories. (e.g. "Camera calibration", "Point cloud")
- **Interdisciplinary keywords:** KW that don't have any specific subject to which they either belong or are strictly related to. (e.g. "Topics", "Digital", "Challenges")
- **Keywords related to Data Management:** KW related to Data Retrieval, Management of Digital Humanities Databases etc. (e.g. "Data mining", "Data retrieval")
- **Methodology keywords:** KW related to the specific methodologies employed in the different research processes and used in the several sources (e.g. "Qualitative", "Survey methodology")
- **Specific keywords of the article:** KW related to the select topics of the article. Some of them were not that easy to link to the topics of the detected Degrees of Freedom (e.g. "Etnography", "Deep convulsional neural networks").

Subject of the Keywords	Number of Keywords	%
3D Reconstruction	30	24,39%
Visualisation	15	12,20%
Literature Survey & Methodologies	19	15,45%
Art History	12	9,76%
Databases / Data Management	9	7,32%
Cultural Heritage	18	14,63%
Design	8	6,50%
Psychology	5	4,07%
Other Specific Subjects	7	5,69%
Total	123	100%

Table 5. Clustering of the keywords by subject.

Another necessary specification regarding 123 Keywords are the specific disciplines to which these keywords are associated.

In fact, defining the type and the frequency of the keywords is not sufficient to specifically understand how Degrees of Freedom can be composed. From this analysis, we deduce that most of the keywords are related to the main topic of 3D reconstruction and visualization/experience of the representation. (Table 5)

4. FINDINGS

The research mainly focused on understanding the meaning of each Degrees of Freedom in the discipline of the article in which it was identified. This type of approach helps to understand how different specific terms can be interpreted by different disciplines.

The interesting aspect of these categories is the way in which they are employed within an interdisciplinary methodological framework that considers their various facets and then defines these Degrees of Freedom in the 3D reconstruction environment with the idea of rendering them recognizable in the digital environment.

4.1 Results & Data

The research of Degrees of Freedom can lead to an understanding of how the same concepts (Degrees of Freedom) can be interpreted differently depending on the subject they are referring to. During the analysis of the materials by means of Mayring's qualitative methodology, the MAXQDA software was highly beneficial since it has been developed to support coding operations. Through the coding strategies 9 Degrees of Freedom were defined. In particular, the coding process led to the identification of 1248 codes within the 41 analyzed articles. Moreover the grouping of codes with the same subject matter between different articles identified the Degrees of Freedom and how they are conceived by the different disciplines. Among the 1248 codes identified, 23 codes are excluded from the analysis because they do not contain information useful for research. Among the identified segments it is possible to specify the reference subjects. In fact, the acquired codes are divided as follows between the several analyzed disciplines: 82 codes related to Cultural Heritage & Digital Technologies, 39 to Gestalt Theory, 272 paragraphs related to Architecture and Planning, 416 paragraphs detected in Art History materials in relation to Caspar David Friedrich and Romantic Art, 331 paragraphs related to Digital Art History and 3D single view reconstruction, 80 paragraphs related to Virtual Reality and UX in VR and AR, and finally, 130 codes related to 3D reconstruction in architectural environments and for cultural heritage. From the results of the analysis of these paragraphs in the literature, it is possible for us to scrutinize the different examples of how these Degrees of Freedom are conceived by the various disciplines.

4.2 Degrees of Freedom: interdisciplinary definition

In order to provide example of what is meant by Degrees of Freedom, 9 Degrees of Freedom have been organized into a table that allows for comparison between different conception of the same Degrees of Freedom in multiple disciplines. This kind of Literature Survey process can be considered from many other points of view, and therefore the same Degrees of Freedom could also be examined through the lens of other disciplines. In order to provide an interdisciplinary definition of Degrees of Freedom, they have been systematized in a table. In this table are gathered examples of codes derived from the qualitative content analysis to convey a particular idea of how that Degrees of Freedom could be defined by a precise topic area.

Freedom Degree	Architecture	Art History	Digital Art History
Spatial and Perspectival arrangements		"[...]While there is already something dreamlike in this combination of motifs, the spatial leap between the esplanade in the foreground and the distant background very much makes the view of the town look like a picture within a picture" (Grave 2012, P. 212)	"[...]Specifically, the beginning of fifteenth century marked a new movement in painting, one important element of which was the increased emphasis on balanced compositions: Not only the colours but also the geometry and form of objects should be realistic and seemingly "correct", i.e. physically plausible." (Lourakis, M., Alongi, P., Delouis, D., Lippi, F., Spadoni 2007, P. 3)

Table 6. Spatial and Perspectival arrangements

Spatial and perspectival arrangements. The standpoint of art history considers the handling of space as a scenic component in relation to the observer (Grave, 2012). Digital Art History strictly focuses on the geometric rules of perspective for the reconstruction of a depicted scene (Lourakis, Alongi, Delouis, Lippi and Spadoni, 2007). In 3D modelling, this Degree of Freedom is linked to the management of a view, which brings into play the observer's field of view and the management parameters of a view in a 3D modeler.

Freedom Degree	Architecture	Art History	Architectural Survey
Conception of detail	"[...]So, we wanted to convince other people that it was looking good. So, we built the big model, and then we took this detail and we brought it back to the small model, and we said: 'Okay, that's how we are going to determine it.'" (Yaneva 2005, P. 884)	"The viewer is confronted with the fact that the desire to see more can lead to seeing nothing in particular, nothing that one can identify." (Grave 2012, P. 86)	"[...]The paintings inside the nave were 3D documented using photogrammetry and processed in Agisoft Photoscan to obtain their 3D qualities and the related ortho-photos necessary for the completion of steps two and four in the pipeline. A total of 395 pictures were taken with a Canon EOS 6D camera at a resolution of 2,048 x 1,365. The main purpose of the photogrammetry model was to create a high-resolution texture of 16,384 x 16,384 and not the use of the model itself, having the more reliable scan data available. In a final step, the texture of the documented surfaces was applied on the 3D model of the nave previously created from the scan data and then divided into five parts to enable the next steps in the pipeline. (If the space in which the visibility analysis is conducted is not preserved anymore or it is not accessible for 3D documentation, then a 3D virtual reconstruction is necessary, along with the simulated lightning conditions required in step 3 of the pipeline—see below.)" (Polig, M., Papacharalambous, D. G., Bakirtzis, N. and Hermon, S., PP. 6-7, 2020).

Table 7. Conception of detail.

Conception of detail. As far as the fragment about architecture is concerned, the level of detail becomes a physical and management element of the project, even simply as a scale of representation of the project (Yaneva, 2005). In the passage related to art history, detail is an element that becomes strategic in the composition to attract the observer's attention (Grave 2012). In the fragment concerning Digital Art History, detail becomes a vital element to create an image retrieval system to search a database of images (Lang and Ommer, 2018). As far as 3D modelling is concerned, the level of detail of the model is linked to the purpose of the representation and to the scale of representation of the model. In particular Alkhoven states that "the level of detail is strongly dependent on what purpose the computer model will serve. The distance from which the model is to be viewed is a determinant of how detailed the model must be" (Alkhoven, 1991, p. 552).

Freedom Degree	Architecture	Art History	Architectural Survey
Relationships in 2D compositions	"[...]The design of a floor-plan is a stage within the architectural design process that takes place between the "schematic design" phase and the "design development" phase. Figure 1 shows a single house, its architectural floor-plan layout and the abstraction of relationships between spaces" (Lobos, and Donath, 2010 P. 137)	"[...]That there is not, to the critic's dismay, a stronger sense of spatial depth is due not least to the unusually rigorous pictorial structure and composition that prove, on closer examination, to be whisly oriented towards the picture-plane. The main motifs of the painting are placed so exactly on the canvas that they coincide with the lines that would define its golden section." (Grave 2012, P. 93)	

Table 8. Relationship in 2D compositions

Relationship between elements in 2D compositions. In the architectural conception of a plan the relationship between the elements is defined by the functioning of the floor plan and the

orientation of the building (Lobos and Donath, 2010). In the passage on Art History, the idea is underlined that the painter conceives the artwork in the relationship between the elements on the painting's surface (Grave, 2012). Concerning 3D modeling the reconstruction of a view, and so the relationships between his components, is achieved once it is possible to understand if we are able to place the elements with certainty into the tridimensional digital space.

Freedom Degree	Art History	Digital Art History	Virtual / Augmented Reality
Perception of the representation	"[...]With the tranquil gaze into the distance of the man in the Old German coat, but above all with the sight of the sea that the viewer can also enjoy, this painting presents a fascinating alternative and, in so doing, makes a plea for more subtle, sensory perception. [...] Friedrich always combines the view of a carefully constructed landscape composition with a reflection on seeing, which is prompted by the fact that the rear-view figures cast us in the role of a second-order observer." (Grave, 2012, P. 222)	"[...]Textured 3D models constitute a new and exciting way for perceiving and appreciating paintings. Their viewer can experience a feeling of immersion; paintings are no longer perceived as static artefacts from a long-gone past but as living, vibrant entities. With the aid of appropriate software, the viewer can literally dive into the painting, interacting with it and observing it from various viewpoints in impressive walk-throughs and inspiring fly-bys. This enables non-specialists to step into history and experience the scene in the space and time frame perceived by the artist" (Lourakis, M., Alongi, P., Delouis, D., Lippi, F., Spadoni 2007, P. 2)	"[...]If at the beginning the studies involved on unavoidable problems of computer graphics—we remember the example of the model of the abbey of Cluny, made by IBM France in 1992—, through the years the technological progress of 3D modelling and rendering, especially real time rendering, has favored the development of virtual reality, in particular of virtual heritage that combines information and communication Technologies with the field of architectural heritage; moreover the technologies of augmented reality contribute to implement immersive, dynamic and interactive experiences. Virtual reality allows the interacting simulation and real-time processing of all the information that is contained in the model; this aspect promotes the development and diffusion of virtual museums." (Centofanti M., Brusaporci S., Lucchese V., 2014, P.35)"

Table 9. Perception of the representation

Perception of the representation. In the passage about Art History, perception is conceived as something that could be guided and influenced by the choices of the painter ("as August Wilhelm and Caroline Schlegel once wrote, the landscape painter "teaches us to see. Droll, that we can so thoroughly forget how to do that." (Grave 2012, p. 222). In Digital Art History, through the Single-view reconstruction, the concept is conveyed that, once a painting has been transformed into a 3D reconstruction of it, it acquires the feature of being investigated from different perspectives and it gives alternative perceptions of the painting (Lourakis, Alongi, Delouis, Lippi and Spadoni, 2007). As far as Virtual and Augmented reality are concerned, the two aforementioned visualization tools are able to implement and strengthen the immersive experience of the representation. In 3D modeling, those features are treated both spatially (a 3D model can have a scope of 360 degrees) and functionally. In fact, the modeler handles the perception of the model in order to achieve the goal of showing particular views of the represented object (Brusaporci, 2013).

Freedom Degree	Architecture	Art History	Digital Art History
Scaling and relationship between volumes in the composition	"[...]Their material dialogue takes into account dispositions, resistance, stability and other properties that change proportionally with scale. In the scaling venture, two alternative states of the building are simultaneously achieved and maintained: a state of being "less-known", abstract and comprehensive; and a state of being "more-known", concrete and detailed. After multiple up and down transitions between small- and large-scale models, the building emerges, becomes visible, material and real. These scaling trials bring the building into existence." (Yaneva 2005, P. 867)	"[...]Whereas the sequence of ice flows in the foreground at first looks like a flight of steps, leading the viewer into the polar landscape, in comparison to the sailing ship these blocks of ice appear to be monstrously large and terrifying in the extreme. However, as soon as the size relations in the painting start to appear questionable, the viewer loses important points of reference that would allow him to determine his own standpoint in the landscape." (Grave J., 2012, P. 198)	"[...]For instance, around 1988, Marilyn Levin began planning an interactive three-dimensional recreation of Piero della Francesca's Legend of the True Cross at Arezzo. As she saw it, formats such as slides gave uniform scale to all images, unintentionally eliminating important aesthetic and experiential differences. The aim of the Piero project was to "present an electronic surrogate for the configuration of the fresco paintings as they appear to a visitor in the church," which would incorporate natural color, relative scale, and physical environment." (Zweig B., 2015, P. 45)

Table 10. Scaling and relationship between volumes in the composition

Scaling and relationship between volumes in the composition. Scaling in architectural design assumes many roles. It can in fact be a tool for knowledge, research, verification or even management of the design process. In particular, the passages of scale allows the designer to have a greater knowledge and control of the project at different scales (Yaneva, 2005). In the passage on art history, it is emphasised how an inconsistent relationship of scale can lead the observer

of a work of art into a state of disorientation concerning the scene of the painting (Grave, 2012). In contrast, in the context of Digital art history, scale plays an experiential role in the enjoyment of a painting and therefore the idea of reconstructing a depicted scenery in 3D would remove its scaling definition (Zweig, 2015). For 3D modelling, the concept of scale is defined by the purpose of the model, the level of detail that one wants to give to the model itself, and the things that someone wants to show on the representational level. In digital space, we typically work at real scale, maintaining a level of detail congruent with the final product we want to achieve according to the criteria mentioned above.

Freedom Degree	Architecture	Art History	Architectural Survey
Representation of the architectural subject	"[...]The communicative flow offered by the model's iconic textuality, coupled with its easy manipulability and interrogability, make it a powerful yet friendly interface for accessing and analysing information. Unlike text structures, this is a simultaneous communication flow, which proceeds according to frames operated by zooms, intersections, transparencies, spatial and temporal jumps. A flow that finds its structural logic in the three-dimensional architecture of the model." (Brusaporci, 2013, P. 22). Translation by A. Esposito	"[...]But can we, as viewers contemplating the painting, also have access to the same vision as that seen by the figures in the painting? Or is it perhaps only our privileged view that allows us to see a perfect, painterly configuration of the architectural structures? Both paintings confront us with the paradox that, even as they present us with a vision-like sight, the presence of the rear-view figures prompts us to reflect on what we are seeing." (Grave, 2012, P. 216)	"[...]The processing of the laser data was carried out using the PolyWorks sw, producing both a three-dimensional reconstruction of the site and the extraction of a series of architectural information. This result made it possible to metrically represent a site of a complexity that is difficult to survey in its totality using other techniques." (Costantino, Angelini, Caprino, 2007, P. 4)

Table 11. Representation of the architectural subject.

Representation of the architectural subject. This Degrees of Freedom was defined thanks to the large amount of literature that has been read on the subject and above all taking into consideration the fact that this Degrees of Freedom was derived from the work of Caspar David Friedrich. Indeed, the way in which Friedrich treats architectural artefacts turns out to be very expressive and unrestrained, always striving to privilege the communicative aspect and to use architecture as a communicative vehicle (Grave 2012). An architectural object is rendered through the action of drawing and modelling and the architect exploits those "tools" to understand and analyze the result of his design. In particular, the tridimensional model gives the opportunity to scope and communicate the project in a more direct and streamlined way (Brusaporci, 2013). The representation of an architectural complex is the last output of an architectural survey campaign and it is one of the most vital assumptions that a surveyor has to consider when approaching the survey of a building. In fact, the measurement strategies will be decisive to define the optimum representation methodology to communicate the heritage of the building (Costantino, Angelini and Caprino, 2007).

Freedom Degree	Architecture	Art History	Urban Reconstruction
Texturing and coloring: Surface Characterization	"[...]Texture mapping is one of the most successful techniques in high quality graphics. It is a method for "painting" texture to the surfaces of objects and its use can immensely enhance the visual richness and realism of graphical models by providing a means of creating the appearance of complexity without the burden of modelling and rendering every detail of a 3D surface. Textures can easily provide additional detail to what would otherwise be flat surfaces with a relatively small increase in computational overhead. A texture is an image that is loaded from a file and applied (mapped) to a surface of 3D model. The so-called texture coordinates are the means for associating a texture image with rendered geometry. Texture coordinates define a mapping between points on a 3D surface and texture image pixels. In the case of planar faces defined by lists of vertices such as those employed in RECOVER, the assignment of texture coordinates to each of their vertices suffices for determining the texture coordinates of all other points lying on planar faces." (Lourakis, M., Alongi, P., Delouis, D., Lippi, F., Spadoni 2007, P. 8)	"[...]Textured 3D models constitute a new and exciting way for perceiving and appreciating paintings. Their viewer can experience a feeling of immersion; paintings are no longer perceived as static artefacts from a long-gone past but as living, vibrant entities." (Lourakis, M., Alongi, P., Delouis, D., Lippi, F., Spadoni, 2007, P. 2)	"[...]The transformation of the historic town will be visualised in a space-time computer model in which bitmap textures enable us to display complex and relatively large architectural objects in detail. This three-dimensional descriptive model allows us to survey and analyse the history of architecture in its reconstructed context" (Alkhoven, 1991, P. 549)

Table 12. Texturing and coloring: surface characterization

Texturing and coloring: surface characterization. The characterisation of the surface in any two-dimensional representation to a three-dimensional representation is achieved through the creation of textures, as described in the code about

texture mapping (Remondino and El-Hakim, 2006). In truth, through this method, it is possible to attach a photo-plane to a 3D model. In architectural planning, texture allows the modelled surfaces to accurately render the aesthetics of the modelled surface. In digital art history, this quality can be exploited to enhance the immersive feature of the reconstruction of a depicted scene. While concerning architectural survey, texture can be obtained from a wide variety of sources. Coloring can be used for diagnostic or historical reconstruction (Alkhoven, 1991). In the environment of the digital 3D reconstruction, the usage of texture mapping can be more incisive for the rendering of colored surfaces and the weave of the canvas (Bernardi and Cristofolini, 2019).

Freedom Degree	Architecture	Art History	Architectural Survey
Lighting	"[...]Solar: To place the rooms in the optimum place and orientation in relation to the sun. Objective: To assure natural illumination to the largest amount of rooms of long stay. Unit: vector. (ii) Views: To place the spaces in the optimum place and orientation in relation to the views. Objective: To assure the best views of the landscape or the surroundings to the long-stay rooms. Unit: vector." (Lobos and Donath, 2010 P. 139)	"[...]Amongst snow-covered tombstones and burial mounds stand the remains of a Gothic church, surrounded by ancient oak trees. The sun has set, and, glowing in the twilight above the ruins, are the evening star and the moon in its first quarter. Thick mist covers the earth, and while the upper part of the masonry is still clearly in view, further down the forms become ever more unclear and indistinct, until in the end everything, the closer it is to the earth, is lost in the mist. The oaks stretch their arms upwards out of the mist, while they disappear completely lower down." (Grave, 2012, P. 152)*	"[...] The active optical sensors most commonly used in architecture and the cultural heritage field are laser scanners (ground or airborne) and fringe projection (or structured light) systems. These measuring instruments consist of a light source and a sensor that registers the response of the laser light on the surface being illuminated." (Remondino, 2011, p.95). Translation by A. Esposito

Table 13. Lighting.

Lighting. It is one of the features related to both the experience and rendering of the representation. As far as architectural conception of lighting is concerned, it is important to mention that light in architectural design could be conceived as a design tool, for example, as far as the orientation of a building is concerned (Lobos and Donath, 2010). In this case, the illumination of the building could be considered either as a modeling tool for the interior design or for the facade of the building or as an energy supply tool for the architectural structure. In Caspar David Friedrich's, the conception of lighting is linked with the environment that the artist delivers through the painting. In particular, Friedrich uses lighting to convey religious meanings and to underline the presence of God in the depicted scene (Grave, 2012). As far as architectural Survey is concerned, light becomes a tool to ease the measurements on site and light is indeed the tool through which the physical measurement operation is delivered (Remondino, 2011; Cantatore, Lasorella and Fatiguso, 2020). In 3D modelling, light plays a key role in the rendering of the model, and therefore in the actual output of the digital reconstruction. At the same time, natural or artificial light can be easily simulated in the modeler. Its position, intensity and colour can be adjusted to the user's requirements.

Freedom Degree	Architecture	Architectural Survey	Virtual / Augmented Reality
Visualization and Management of the Representation	"[...]Three-dimensional modeling of objects and scenes is an intensive and long-lasting research problem in the graphic, vision and photogrammetric communities. Three-dimensional digital models are required in many applications such as inspection, navigation, object identification, visualisation and animation." (Remondino F, El-Hakim, S., P. 269, 2006)	"[...]The cognitive act is the experiential act. But it is the lived experience of the event as a sequence of spatial/temporal events, up to the event in the present that sums up all the previous ones. The model thus expresses — in the sense that it contains — the history and the passage of time of the situation explored from its conception, to its creation, to its transformations, up to the current period: historic/synchronic and diachronic sections, reconstructions and/or visualizations of modified situations, or intentions and prefigurations never actually implemented, or simply narrated." (Centofanti M., Brusaporci S., Lucchese V., 2014, P. 33)	"[...]Thanks to developments in the field of sens- sories, it is possible to acquire large quantities of spatial data, geo-reference them and derive 3D information quite easily. We are increasingly seeing virtual restorations with 3D environments and visualisations produced for various applications such as documentation, conservation, virtual restoration, simulation, didactics, animation, cartography, spatial management (GIS), monitoring, etc." (Remondino, 2011, p. 91). Translation by A. Esposito

Table 14. Visualization and management of the Representation

Visualization and Management of the Representation.

Visualization and representation management are both very general topics and are defined in very different ways across different subjects. In particular, this Degrees of Freedom differs from the perception of representation because it consists of the preparation of the material for use by the stakeholder or user. In architecture, the use of 3D models has led to many visualizations that are available to both the designer and the user to inspect and analyze spaces (Remondino and El-Hakim, 2006). Digital Art History has always discussed and considered the enriching factor of pictorial material through three-dimensional visualization (Drucker, 2013). Virtual reality acquired from a 3D reconstruction can be used to experience, analyze, study virtual scenarios of the reconstructed item. Visualization in the three-dimensional mode enhances the narrative quality of an architectural model of a cultural heritage building (Centofanti, Brusaporci and Lucchese, 2014). The selected codes provide an explanation of how the same Degrees of Freedom can be defined differently depending on the discipline. The examples of codes have been compared in order to understand how the Degrees of Freedom can be interdisciplinarily defined in a three-dimensional space.

To summarize: this explorative project, through the method of qualitative content analysis method, in the environment of the 2D representation and 3D reconstruction, arrived at the following two key products:

- The systematization of the interdisciplinary definition of the different Degrees of Freedom in the corresponding subject and the definition of the Degrees of Freedom in the 3D Modeling context.
- A definition of Degrees of Freedom through the analysis of sources based on subjects related to the 2D and 3D representation and to the depictional motifs of Caspar David Friedrich. They are now ready to be tested as evaluative categories to understand to which extent 3D Modeling can be an effective methodology for analyzing the depiction and the inconsistencies in the representation of Friedrich's paintings.

Concerning this present study, it is significant to mention some limitations owing to the methodology employed. For instance the source retrieval method can lead to potential errors. In fact, the use of precise research terms in the different source browsers can lead to find publications that are related to other topics and with other keywords defining the topic of the article.

5. CONCLUSION & FURTHER RESEARCH

This article describes an exploratory approach using Mayring's qualitative research methodology to obtain categories for analyzing the transition from a two-dimensional to a three-dimensional representation. The derived categories, considering that the set of sources can be extended, can likewise be implemented and characterised in increasing detail given different facets. The most intriguing possibility that follows from this is the examination of such Degrees of Freedom within the digital space by comparing the acquired categories with the practical experience of modeling the depiction within the digital space.

These Degrees of Freedom, can be employed as assessment categories for the reconstruction of the depicted sceneries. They can be compared with new Degrees of Freedom derived from the practical experience of modelling Caspar David Friedrich's artworks. The dialectic defined in this way compares a theoretical approach based on an analysis of the literature, and a practical approach to understanding whether the categories

obtained with the first method can be verified, questioned, or extended.

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REFERENCES

Alkhoven, P., 1991: The Reconstruction of the Past: the Application of New Techniques for Visualisation and Research in Architectural History. *Computer Aided Architectural Design Futures: Education, Research, Applications, CAAD Futures '91 Conference Proceedings*. Zürich (Switzerland), July 1991. 549-566. <http://papers.cumincad.org/cgi-bin/works/Show?2560>.

Bernardi, F., Cristofolini, A., 2019: Dal dipinto alla modellazione 3D. Sperimentazione sullo spazio proiettivo attraverso strumenti di rappresentazione digitale. In: *Riflessioni / Reflections l'arte del disegno/il disegno dell'arte*. UID – Unione Italiana per il disegno, edited by Paolo Belardi, 2019, Gangemi. 1063-1070.

Brusaporci, S., 2013: Modellazione e rappresentazione digitale per i beni architettonici. In: *Modelli complessi per il patrimonio architettonico-urbano*, edited by Mario Centofanti and Stefano Brusaporci, 2015, Gangemi Editore. 18-24.

Cantatore, E., Lasorella, M., Fatiguso, F., 2020: Virtual reality to support technical knowledge in cultural heritage. the case study of Cryptoporticus in the archaeological site of Egnatia (Italy). *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLIV-M-1-2020, 2020 HERITAGE2020 (3DPast | RISK-Terra) International Conference, 2020.

Centofanti M., Brusaporci S. & Lucchese, V., 2014: Architectural Heritage and 3D Models. In: *Computational Modeling of Objects Presented in Images: Fundamentals, Methods and Applications*. Edited by Paolo Di Giamberardino, Daniela Iacoviello, Renato Natal Jorge and João Manuel R. S. Tavares, 2014, Springer. 31-49.

Costantino, D., Angelini, M. G. and Caprino, G., 2007: Rilievo integrato per ricostruzione 3D e analisi speditiva degli affreschi - Cristo la Selva. *Atti 11a Conferenza Nazionale ASITA. Volume I*. Centro Congressi Lingotto, Turin (Italy).

Criminisi, A., Kemp M. and Zisserman A., 2002: Microsoft Research Microsoft Corporation Bringing Pictorial Space to Life: computer techniques for the analysis of paintings. *Proceedings of the 2011 SIAM International Conference on Data Mining (SDM'2011)*. 1-14.

Daintith, J. and Rennie, R. 2005: *The Facts on File Dictionary of Mathematics (4th edn)*. Market House Books. New York, NY.

Drucker, J., 2013: Is There a "Digital" Art History?. *Visual Resources: An International Journal of Documentation*. 29(1-2). 5-13. DOI:<http://dx.doi.org/10.1080/01973762.2013.761106>.

Grave, J., 2012. *Caspar David Friedrich*. Prestel.

Lang, S., Ommer, B., 2018: Attesting similarity: Supporting the organization and study of art image collections with computer vision. *Digital Scholarship in the Humanities* 33 (4), 846–856 .

Lobos, D., Donath, D., 2010: The problem of space layout in architecture: A survey and reflections, *Arquiteturavista*, 6 (2), 136-161.

Lourakis, M., Alongi, P., Delouis, D., Lippi, F., Spadoni, F., 2007: RECOVER: photorealistic 3D reconstruction of perspective paintings and pictures. *EVA 2007 London Conference*, London, United Kingdom.

Mayring, P., 2000: Qualitative Content Analysis [28 paragraphs]. *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*, 1(2), Art. 20.

Polig, M., Papacharalambous, D. G., Bakirtzis, N., & Hermon, S., 2020: Assessing Visual Perception in Heritage Sites with Visual Acuity: Case study of the Cathedral of St. John the Theologian in Nicosia, Cyprus. *ACM Journal on Computing and Cultural Heritage*, 14(1), 1-18.

Remondino, F., 2011: Rilievo e modellazione 3D di siti e architetture complesse. *Disegnarecon, tecnologie per la comunicazione del patrimonio culturale*, Università di Bologna, Volume 3, 90-98.

Remondino, F., El-Hakim, S., 2006: Image-based 3d modelling: a review. *The Photogrammetric Record*, 21(115). 269–291.

Saldana, J., 2009: *The Coding Manual for Qualitative Researchers*, Sage Publications.

Yaneva, A., 2005. Scaling Up and Down: Extraction Trials in Architectural Design. *Social Studies of Science*, 35(6), 867–894.

Zweig, B., 2015: Forgotten Genealogies: Brief Reflections on the History of Digital Art History. *International Journal for Digital Art History*, 1 (1), 39-49.