

## The analysis of the lighting and shading configuration in an urban landscape depicted by Caspar David Friedrich.

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### Abstract

This study analyses how Caspar David Friedrich depicted natural illumination in an urban space in his 1818 watercolour, *Greifswalder Marktplatz mit der Familie Friedrich*. Developing a workflow that uses digital methods such as 3D modelling and image editing of raster and vector images, the study analyses how the Greifswald painter interpreted the shading of the market square scene in his hometown. Having modelled the Greifswald square in the period when Friedrich is presumed to have painted his watercolour, the study conceives natural lighting scenarios in the 3D Blender software environment. These scenarios are then used to compare the shading in Friedrich's work with the shadow pass of the square model, which was created from heterogeneous sources. These scenarios are developed by selecting dates relating to 1818, based on bibliographical information about the artist. Once the shadows have been rendered from modelling the square, they are individually compared with the shadows in Friedrich's painting to understand how closely the digitally created lighting scenario matches the painter's representation. The study aims not only to identify the timespan in which the painter could have depicted the watercolour, but also to analyse Friedrich's methods of representing natural light in detail, considering any patterns, peculiarities and, above all, inconsistencies.

### 1. Introduction

Caspar David Friedrich's depictions of urban spaces have often been limited to silhouettes of cities, enhanced with certain artistic stylisations to make them stand out within the composition of the painting. These techniques were primarily concerned with the way the city skyline was illuminated within the composition (Tzeng, 2017). An important relationship exists in Friedrich's body of work between the depiction of cities, city spaces, and their representation in terms of lighting.

#### 1.1 The analysed artwork: *Greifswalder Marktplatz mit der Familie Friedrich*.

This provides the context for studying Caspar David Friedrich's *Greifswalder Marktplatz mit der Familie Friedrich* (Figure 1) in which the artist depicted his hometown market square 'from the inside'. The scene is believed to have been painted in 1818, during Friedrich's journey with Caroline Bommer to Greifswald (Börsch-Supan & Jähnig, 1973, pp. 350-351).

It is also worth mentioning that Friedrich executed study sketches (*Studienzeichnungen*) on site that would later be reworked and reassembled in the artist's studio. The literature testifies to the fact that the Greifswald painter was in the habit of indicating the position of the light source that was in relation to the depicted object (Busch, 2003). The purpose was to enable it to be more accurately depicted on the canvas later. The well-defined shadows cast on the buildings and ground allow for the analysis of lighting and shading. This makes the painting particularly suitable for such a study.



Figure 1: Caspar David Friedrich, *Greifswalder Marktplatz mit der Familie Friedrich*, 1818, Watercolour, pen, graphite pencil, 54,5 x 67 cm, Pommersches Landesmuseum, Greifswald. © Stiftung Pommersches Landesmuseum, Greifswald.

According to the drawings in Grummt's publication (Grummt, 2011), the painter was in Wolgast (Grummt, 2011, p.739, no. 808) on 1 July 1818, and in Vierow bei Lubmin (Grummt, 2011, p.740, no. 809) on 3 July. There is no indication of Friedrich's whereabouts from 3 July to 4 August. Finally, some sketches (Grummt, 2011<sup>1</sup>) reveal the artist's presence in Greifswald from 17 to 20 August 1818 (Richter, 2024, p. 404). The artist's use of natural light in the composition of this urban scene was analysed by creating lighting scenarios that took this bibliographic information into account.

### 2. Research question

In particular, studying the natural illumination of this urban space using 3D modelling raises a question about the representation of Caspar David Friedrich's shading and natural illumination..

- Is it possible to quantify the difference between Friedrich's representation of the illumination and the natural lighting

<sup>1</sup> Grummt, 2011, p.754, no. 825v; p. 755, no.826v; p.756 no. 827 828; p.758, no. 828v; p. 759, no. 830v)

situation in Greifswald's market square at the time the painter was there?

In order to answer this question, a study was conducted to analyse the shadows in Friedrich's watercolour precisely and compare them with the shadows of the buildings in Greifswald Square at the time he painted them. The buildings were modelled in 3D using historical photographs and other literary sources.

### 3. Materials and Methods

#### – 3D Modelling.

Approaching shadow research is closely linked with 3D modelling, whether interpreted digitally or analogically. Using a 3D software programme enables us to:

1. The immediate calculation of the shadow generated by modelled objects.
2. Raster processing of the shadows themselves can be obtained for comparison with the shadows in the artwork.

The Sun Position plugin in Blender can be used to reliably recreate lighting settings based on the position of the sun (Figure 2).

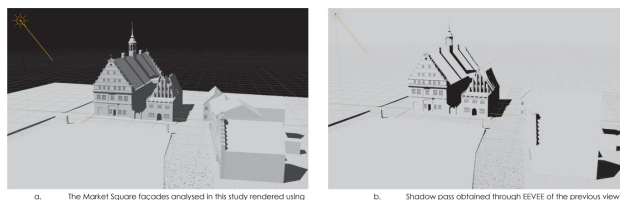


Figure 2: Blender visualisation of the model of the square fronts involved in the analysis with a specific sun position. Elaboration by the author.

#### – Image editing.

Using raster (Adobe Photoshop) and vector (Adobe Illustrator) graphics software makes identifying shadows much easier and more accurate. We use raster software to modify the grey-scale shadow areas of the artwork, and then vectorise them using Adobe Illustrator, which allows us to define the shadow areas sharply. And finally, the actual shadow analysis of the model and the artwork is carried out using Adobe Photoshop with the comparison of the number of pixels forming the shadows.

### 4. Characteristics of the analytical process

The possibility of creating a temporal framework and reconstructing the natural lighting conditions using a digital model leads us to consider two main conditions:

1. Creating different light setting reconstruction scenarios with different times and dates.
2. Identifying the degrees of freedom (Esposito, 2023) that influence the creation of different natural lighting digital scenarios.

Specifically in this case we can identify:

- a) The geolocation of the modelled scene by specifying the latitude and longitude of the scene.
- b) The orientation in the modelled scene
- c) The date and time at which the lighting of the scene is to be reconstructed
- d) The time zone according to the area in which the reconstructed scene is located.

Some of the degrees of freedom mentioned are established *a priori*. In fact, location (a) will be the market square in Greifswald, direction (b) will be north in the modelled scene according to the real-world north, and time zone (d) will be linked to location (a). In the case of Greifswald, this time zone is UTC+2

(as we are in the period between March and October, when Daylight Saving Time must be taken into account).

### 5. Workflow

The workflow for reconstructing the illumination of Greifswald Market Square and comparing it with the model can be achieved in several steps, some of which concern only the artwork and others only the 3D model:

1. Define the vanishing point relative to the building whose shadows are to be analysed.
2. Setting a date and time for creating the simulated lighting.
3. Editing the watercolour image in relation to the considered building.
  - a) Image editing in Photoshop to convert the image to greyscale, highlighting the shadows in relation to the rest of the image.
  - b) 'Vectorisation' of the elements highlighted in the first stage of editing. This process produces a sharp image of the shadows on the building in question.
4. Render of the shadows (shadow pass) using the EEVEE render engine (Figure 3).
5. Segmentation of the shadow areas both within the shadows of the painting and in the shadows of the 3D reconstruction of the square.
6. Using Adobe Photoshop, the different shadows identified in step 6 are compared punctually. Two factors are considered in the shadow analysis:
  - a) Comparison of the two shadow shapes in terms of pixel quantity.
  - b) Comparison of the percentage overlap or difference of the shadows.

The comparison of the two shapes is made by calculating the amount of difference pixels between the two shadows. The more this value of difference between the shadows decreases, the better the reconstructed illumination scenario fits with Friedrich's representation.

However, it must be specified here that the resolution of the images of the shadow pass and the watercolour shadows must be the same.

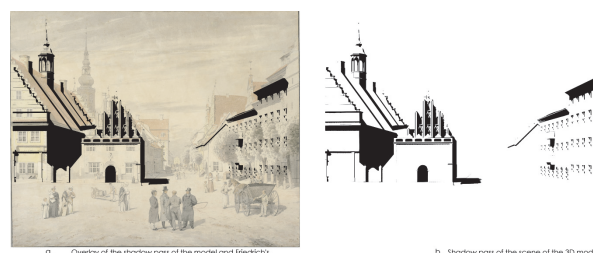


Figure 3: Comparison of the shadow pass overlay on the watercolour surface (left) and the shadow pass obtained from the 3D software (right). On the left side in the background: Caspar David Friedrich, Greifswalder Marktplatz mit der Familie Friedrich, 1818, Watercolour, pen, graphite pencil, 54,5 x 67 cm, Pommersches Landesmuseum, Greifswald. © Stiftung Pommersches Landesmuseum, Greifswald. Edited by the author.

### 6. Natural lighting scenarios and findings

In order to facilitate a precise analysis of the shadows, the artwork and 3D model were divided into three sections. Three main sections relating to the fronts of the square were identified:

- Town Hall (*Rathaus*)
- Building *Markt 1*
- The north side of the Market square.

The analysis will be carried out for each of these fronts by accurately comparing them with the watercolour shadows in these sections.

As explained above, the creation of different scenarios is linked to 2 factors: date and time of the day.

The first step in this analysis is to understand what the vanishing point is, in order to position an observer.

Once the vanishing point has been identified, it should be noted that, in the case of a shadow study, the observer's distance is not important as it does not affect the size of the shadows.

Once the sun has been positioned and the settings configured, it is possible to analyse and compare natural lighting scenarios.

## 6.1 First Scenario (25/07/1818 - h. 12:15. (UTC +2))

The first scenario is defined by attempting to reproduce, at least in general terms, the shadowing effect of the painting. The biographical information mentioned above is also taken into account. Once the position of the observer has been defined, the shadow pass is defined using the Eevee render engine (Figure 4).

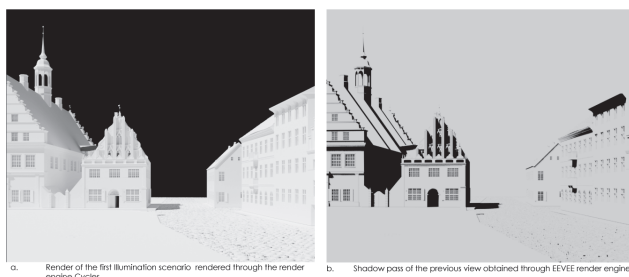


Figure 4: Left side: render obtained using the Cycles render engine. Right side: Shadow pass obtained from Eevee. Elaboration by the author.

### 6.1.1 Town Hall (*Rathaus*)

Once the building had been isolated in the two representations (render and watercolour), the shadows were segmented for individual comparison, since there is a significant discrepancy between the images due to dimensional, geometric and level-of-detail limitations, which will be discussed later.

After the post-production and image-editing steps of the watercolour (Figure 5) that will lead us to identify the remarkable shadows, we will also vectorise the shadow pass obtained by Blender.



Figure 5: Image-editing process of the painting to reconstruct the shadows. Top left and centre: Caspar David Friedrich, Greifswalder Marktplatz mit der Familie Friedrich, 1818, Watercolour, pen, graphite pencil, 54,5 x 67 cm, Pommersches Landesmuseum, Greifswald. © Stiftung Pommersches Landesmuseum, Greifswald. The 2 pictures (centre – right) above: Edited by the author.

Next, we segmented the remarkable shadows in preparation for analysing them to study their compatibility with the watercolour of the 3D scenery (Figure 6).

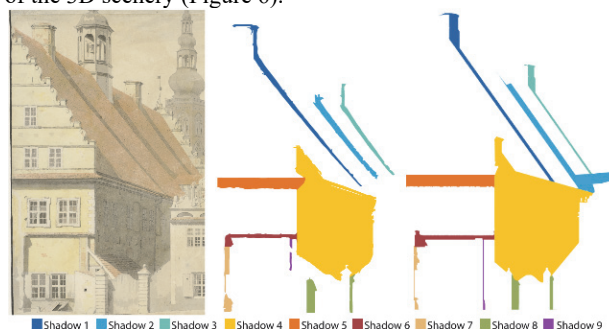


Figure 6: Comparison between the segmentation of shadows in the painting (centre) and the segmentation of the shadows of the 3D modelling of the Town Hall (right). On the left: Caspar David Friedrich, Greifswalder Marktplatz mit der Familie Friedrich, 1818, Watercolour, pen, graphite pencil, 54,5 x 67 cm, Pommersches Landesmuseum, Greifswald. © Stiftung Pommersches Landesmuseum, Greifswald. Edited by the author.

The shadow analysis was carried out graphically, and an example of the results can be seen in the Figure 7 below. Subsequently, the table and graphs (Figure 8-10) present the data from the analysis of nine significant shadows in the Town Hall.

First Scenario (25/07/1818 - h. 12:15. (UTC +2))			
Shadow	Watercolour	3D Reconstruction	Overlap / Difference
1			

Figure 7: Ordered two-way comparison of Shadow 1 of the Rathaus, both in the painting and in the 3D reconstruction model. The pixels that do not overlap between the two shadows are shown in green. Edited by the author.

Shadow No.	Model (px)	Painting (px)	Difference (px)	Difference (%)
Shadow 1	1790	1439	2242	156%
Shadow 2	1490	936	1352	144%
Shadow 3	784	687	926	135%
Shadow 4	10580	10168	2616	26%
Shadow 5	1574	1497	432	29%
Shadow 6	869	685	579	85%
Shadow 7	331	491	445	91%
Shadow 8	652	745	425	57%
Shadow 9	272	123	298	242%

Figure 8: Summary table comparing Friedrich's watercolour shadows with those of the digital reconstruction of the lighting in the first scenario for the Town Hall.

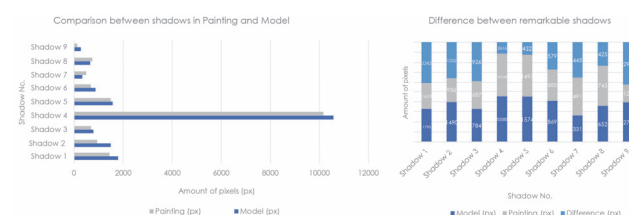


Figure 9: Graphs describing the number of pixels of each remarkable shadow (on the left) and the number of pixels of the two remarkable shadows compared to the number of pixels of the difference between the two shadows (on the right side).



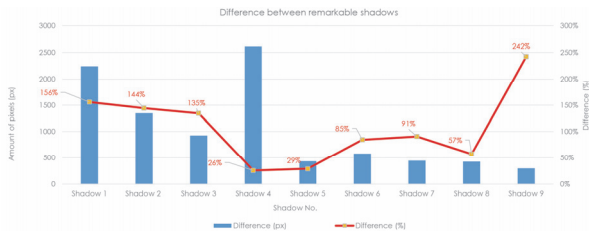


Figure 10: Graph showing the percentage difference between remarkable shadows and the difference in number of pixels between the shadows themselves.

- There is an important difference to note: the contrast between the shadows on the roof section is much greater than that on the building's façade. This could indicate an inconsistency in how shading is represented.
- The very high percentages of difference are due, in the case of shadows 1, 2 and 3, to their different angles of inclination with respect to the watercolour.

### 6.1.2 Building "Markt 1"

The building to the right of the town hall is shown here in its original late Gothic layout, consisting of two floors and a pier gable. This was subsequently modified in a neo-Gothic style. We will now proceed directly to the analysis of the building's shadows. Figure 11 shows the image editing process used to identify the remarkable shadows on which the analysis will be based.

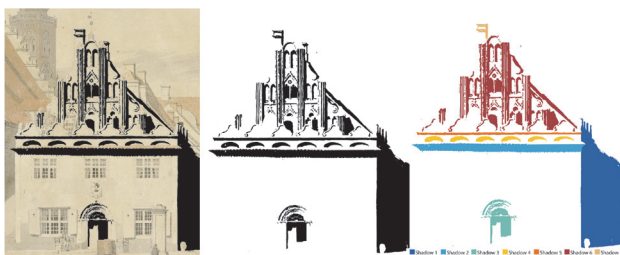


Figure 11: Image-editing process of the painting to segment the remarkable shadows and overlay of the remarkable shadows of the watercolour. Top left: Caspar David Friedrich, Greifswalder Marktplatz mit der Familie Friedrich, 1818, Watercolour, pen, graphite pencil, 54,5 x 67 cm, Pommersches Landesmuseum, Greifswald. © Stiftung Pommersches Landesmuseum, Greifswald. Edited by the author

Here in the analysis there will be an important factor that will greatly influence the results: the large dimensional difference between the two representations, the building depicted by Friedrich being larger than the one reconstructed in 3D. This is recognisable from the following figure 12.

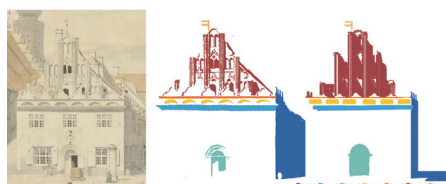


Figure 12: Comparison between the shadow passes of the watercolour and the 3D model for the Markt 1 building. On the left side: Caspar David Friedrich, Greifswalder Marktplatz mit der Familie Friedrich, 1818, Watercolour, pen, graphite pencil, 54,5 x 67 cm, Pommersches Landesmuseum,

Greifswald. © Stiftung Pommersches Landesmuseum, Greifswald. The 2 pictures (centre – right) above: Edited by the author

The figures, graphs and tables below (Figures 13–16) show the results of the first lighting scenario for this building.

Shadow No.	Model (px)	Painting (px)	Difference (px)	Difference (%)
Shadow 1	10956	8971	6817	76%
Shadow 2	5444	6256	3210	51%
Shadow 3	5922	2905	3829	132%
Shadow 4	3973	1958	2591	132%
Shadow 5	1256	2350	2391	102%
Shadow 6	29335	17316	25718	149%
Shadow 7	473	319	451	141%

Figure 13: Table describing the shadow size values and their percentage difference. It can be seen that for this scenario, the model shadows diverge from the one of the watercolour.

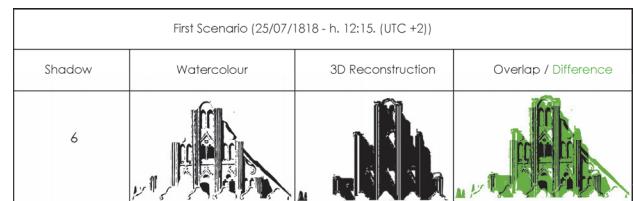


Figure 14: Ordered and two-way comparison between the shadows 6 of Building Markt 1 in the painting and in the 3D reconstruction model. This shadow was selected as an example to emphasise the difference between the shadows. Edited by the author.

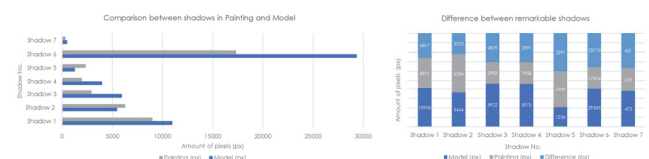


Figure 15: Graphs describing the number of pixels of each remarkable shadow (on the left) and the amount of pixels of the two remarkable shadows compared with the amount of pixels of the difference between the two shadows.

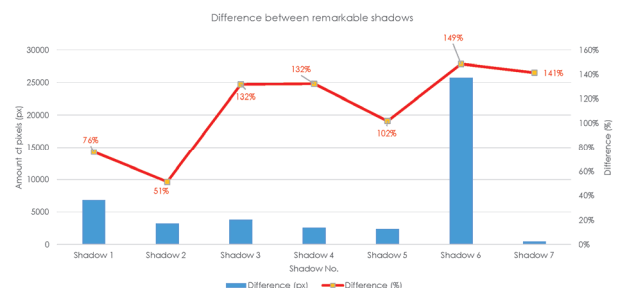


Figure 16: Graph relating the difference in percentage between the remarkable shadows and the difference in number of pixels between the shadows themselves.

In the scenario analysed, this building appears to have very large differences between shadow passes of the 3D model and shadows of the painting. This is mainly related to the dimensional difference between the two representations for the dimensional reason mentioned above.

### 6.1.3 North side of the Market square

The northern section of the square as depicted by Friedrich, when compared with the model, leads us to make two assumptions:

1. There are substantial formal differences between the buildings depicted by Friedrich and those in the 3D reconstruction of the square.
2. Most of the shadows on the architecture are obscured by the trees on the northern side of the square, so the analysis will

focus on three remarkable shadows that can easily be identified.

The following figure 17 illustrates the process for defining the 3 notable shadows for this section of the watercolour..



Figure 17: Image-editing process of the painting to reconstruct the remarkable shadows. Top left and centre: Caspar David Friedrich, Greifswalder Marktplatz mit der Familie Friedrich, 1818, Watercolour, pen, graphite pencil, 54,5 x 67 cm, Pommersches Landesmuseum, Greifswald. © Stiftung Pommersches Landesmuseum, Greifswald. Edited by the author.

With regard to the northern section of the square, it is important to emphasise the difference in representation between the northern façade and the height of the building at the square's corner. In this case, this difference in height leads to a change in the inclination of the roof pitches, resulting in a significant difference in shading. All of this can be seen in the figures 18-19.

Shadow No.	Model (px)	Painting (px)	Difference (px)	Difference (%)
Shadow 1	2473	2386	967	41%
Shadow 2	930	525	1326	253%
Shadow 3	183	124	204	165%

Figure 18: Table describing the shadow size values and their percentage difference. It can be seen that for this scenario the model's shadows are very distant from the watercolour. Shadow 1 is the one that tends to match the shadow pass of the watercolour the most.

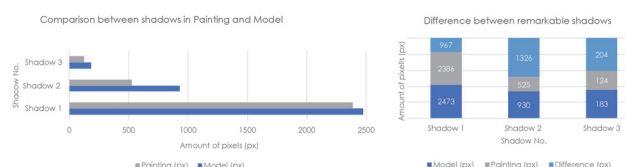


Figure 19: Graphs describing the number of pixels of each remarkable shadow (on the left) and the amount of pixels of the two remarkable shadows compared with the amount of pixels of the difference between the two shadows.

## 6.2 Second Scenario (18/08/1818 - h. 10:00 (UTC +2))

We will briefly describe the other 2 lighting scenarios of the scene. This second date was selected with respect to Richter's dating (Richter, 2024) as it is very likely that Friedrich was in the Greifswald area between 17 and 20 August and may have spent these days in his home town.

The figure 20 below compares the shadow passes of the two reconstructive scenarios.



Figure 20: Comparison of the shadow passes of the two lighting scenarios. Edited by the author.

### 6.2.1 Town Hall (Rathaus)

One of the most interesting aspects of studying different scenarios is certainly to be able to compare the shadow passes of the individual buildings in Friedrich's representation.

In the figure 21 below, the difference between the two lighting scenarios and the shadow pass of the watercolour with regard to Town Hall is analysed.

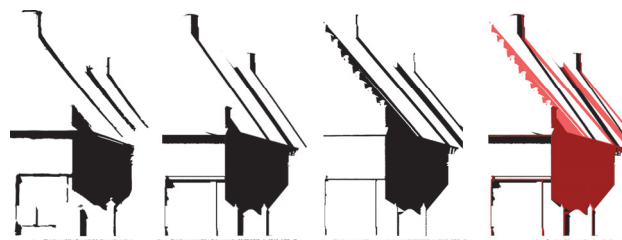


Figure 21: A comparison of the shadow passes of the two lighting scenarios (b-c-d) and the shadow pass of the watercolour (a). Edited by the author.

From these figures 22-25 it is already possible to recognise the large differences in the shape of many shadows.

Let us proceed to analyse the Town Hall shadows for this scenario through the figures below.

Shadow No.	Model (px)	Painting (px)	Difference (px)	Difference (%)
Shadow 1	2225	1439	1399	97%
Shadow 2	1287	936	755	81%
Shadow 3	811	739	972	132%
Shadow 4	13527	10168	4693	46%
Shadow 5	358	1497	1400	94%
Shadow 6	319	685	545	80%
Shadow 7	233	491	466	95%
Shadow 8	330	745	667	81%
Shadow 9	207	123	231	188%

Figure 22: Table describing the size values of the shadows and their percentage difference. It can be seen that almost all shadows (except shadow 4) have high average difference values. Although in shadows 1 and 2, the difference values decreased.

Second Scenario (18/08/1818 - h. 10:00. (UTC +2))			
Shadow	Watercolour	3D Reconstruction	Overlap / Difference
1			

Figure 23: Ordered and two-way comparison of two example shadows in the watercolour and in the 3D reconstruction model. The shadow 1 is highlighted as an example. Edited by the author.

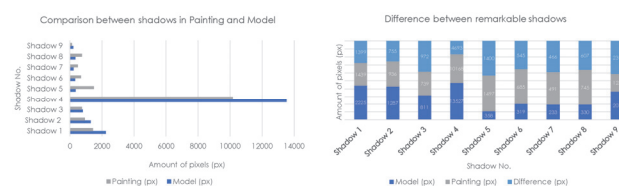


Figure 24: Graphs describing the number of pixels of each remarkable shadow (on the left) and the amount of pixels of the two remarkable shadows compared with the amount of pixels of the difference between the two shadows (on the right side).

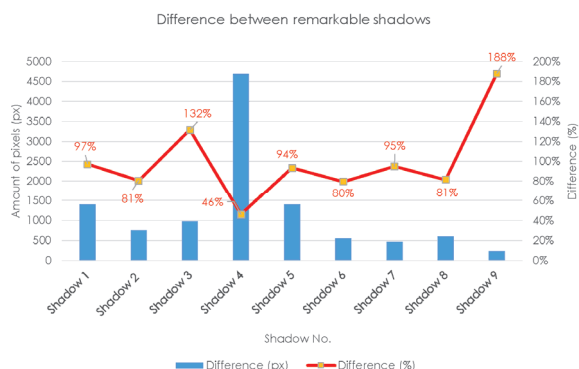


Figure 25: Graph relating the difference in percentage between the remarkable shadows and the difference in number of pixels between the shadows themselves.

Compared to the first scenario, there is a significant average difference in the shadows, which distances this scenario (at least with regard to the Town Hall's shading) from the light setting created by Friedrich.

### 6.2.2 Building "Markt 1"

The scenario we are analysing, at least in appearance, seems to be able to replicate the shading of this building in the watercolour. Let us try to verify whether this is the case by means of the punctual shadow analysis described in the Figure 26 below.



Figure 26: Comparison of the two shadow passes of the Building Markt 1 relative to the two light scenarios created in 3D digital space. Edited by the author.

Important discrepancies can be seen between the two scenarios, particularly at the pier gable on the second floor. In order to understand whether the shadows accurately reflect those of the painting, the following table and graphs (Figure 27-29) need to be analysed.

Shadow No.	Model (px)	Painting (px)	Difference (px)	Difference (%)
Shadow 1	11708	8971	4506	50%
Shadow 2	1485	6256	5541	89%
Shadow 3	3083	2905	2964	102%
Shadow 4	2820	1958	1928	98%
Shadow 5	1626	2350	2095	89%
Shadow 6	9722	17316	17943	104%
Shadow 7	184	319	222	70%

Figure 27: Table describing the magnitude values of shadows and their percentage difference. Compared to the previous scenario, there is a general decrease in the percentage difference between shadows, even though the average difference value remains high.

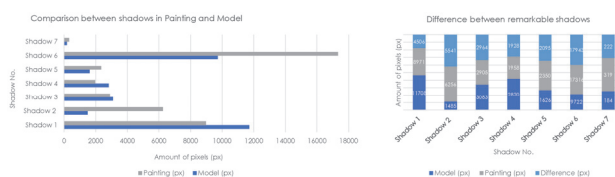


Figure 28: Graphs describing the number of pixels of each remarkable shadow (on the left) and the amount of pixels of the two

remarkable shadows compared to the amount of pixels of the difference between the two shadows (on the right side).

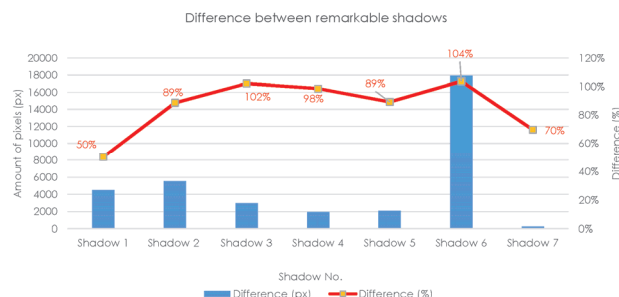


Figure 29: Graph relating the difference in percentage between the remarkable shadows and the difference in number of pixels between the shadows themselves.

In this case, although the difference between the shadows in the painting and those in the model is significant, we still see an average improvement in the percentage difference for shadows 3 to 7.

### 6.2.3 North side of the Market square

Given the previous explanations regarding the workflow and representation of the shadow analysis, a account for this section of the representation will be given via the Table (Figure 30) below.

Shadow No.	Model (px)	Painting (px)	Difference (px)	Difference (%)
Shadow 1	1744	2386	962	40%
Shadow 2	548	525	972	185%
Shadow 3	91	124	119	96%

Figure 30: Table describing the shadow size values and their percentage difference. The situation is very similar to the previous scenario.

In summary, the following assumptions can be made about the results of this second scenario:

- With regard to the Town Hall, we observe an average increase in the percentage difference value of the shadows, whereas for the shadows on the roof of the building, we observe a decrease in discrepancy values. This again emphasises the difference between shading on the façade and on the roof
- Building Markt 1 has an average decrease in the percentage difference between the shadows in this case, but it should be noted that the discrepancy between the watercolour shadows and the 3D reconstruction shadows is still relevant.
- On the north side of the square, the situation is very similar to the one displayed in the previous scenario.

### 6.3 Third Scenario (10/07/1818 - h. 12:00 (UTC +2)).

The third scenario (Figure 31) focuses on a period during which Friedrich was travelling; there is no evidence as to his exact location at this time (the same applies to the first scenario). It is highly probable that he was on his honeymoon, and it cannot be ruled out that he was not in Greifswald between 3 July and 4 August 1818 (Richter, 2024).

After providing an overview of how the analysis works, we will present example figures for this scenario to help you compare it with the watercolour shading and other lighting reconstruction scenarios.





Figure 31: Comparison of the shadow passes of the three lighting scenarios. Elaborated by the author.

### 6.3.1 Town Hall (*Rathaus*)

In this case, the scenario appears to be quite similar to the first one, as both were recorded in July in the morning. Let us confirm this through data analysis. The Figure 32 shows the difference in shadow passes for the different scenarios for the Town Hall. Figure 33 displays the results of the analysis for this building.

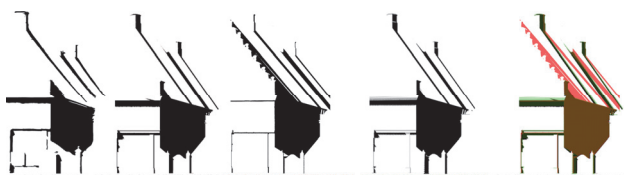


Figure 32: Comparison of the three shadow passes for the three lighting scenarios created in the 3D digital space for the Town Hall and Friedrich's watercolour. Edited by the author.

Shadow No.	Model (px)	Painting (px)	Difference (px)	Difference (%)
Shadow 1	1743	1439	2203	153%
Shadow 2	1311	936	1198	128%
Shadow 3	788	739	921	125%
Shadow 4	9936	10168	2413	24%
Shadow 5	1507	1497	270	18%
Shadow 6	785	685	499	73%
Shadow 7	507	491	495	101%
Shadow 8	744	745	484	65%
Shadow 9	266	123	259	211%

Figure 33: Table describing the shadow size values and their percentage difference. It can be seen that the values are similar to the first scenario.

### 6.3.2 Building "Markt 1"

In the case of the Markt 1 building, we have found a compromise between the first and second scenarios. Nevertheless, the values do not improve significantly compared to the shadows in the painting. The data is shown in the Figure 34 below.

Shadow No.	Model (px)	Painting (px)	Difference (px)	Difference (%)
Shadow 1	11634	8971	5058	56%
Shadow 2	5664	6256	2560	41%
Shadow 3	6214	2905	4121	142%
Shadow 4	4250	1958	2593	132%
Shadow 5	1285	2350	2350	100%
Shadow 6	28709	17316	18539	107%
Shadow 7	428	319	435	136%

Figure 34: The table below shows the magnitude values of the shadows and their percentage difference. As can be seen, the values are similar to those in the first scenario. However, shadows 1 and 2 seem to match the painting more closely. Overall, the values remain high.

### 6.3.3 North side of the Market square

This portion of the watercolour/model also follows the rules described for the previous scenarios with the difference that in the case of the remarkable shadow 1, the values drop to a difference of 24%. For the other data, see the table in the Figure 35 below.

Shadow No.	Model (px)	Painting (px)	Difference (px)	Difference (%)
Shadow 1	2190	2386	544	24%
Shadow 2	472	525	821	156%
Shadow 3	105	124	140	113%

Figure 35: Table describing the magnitude values of the shadows and their percentage difference. Shadow 1 is the one that tends to match the painting more than the other scenarios.

To summarise the results of this third scenario, some assumptions can be made:

- With regard to the Town Hall we find difference values compared to the watercolour very similar to the first scenario.
- Building *Markt 1* again shows very high percentage difference values, but there are decreases in some shadows such as 1 and 2.
- On the northside of the square the situation is very similar to the first scenario but shadow 1 shows a very relevant decrease in percentage difference.

## 7. Conclusions

The detailed study of the shadows for Caspar David Friedrich's watercolour *Greifswalder Marktplatz mit der Familie Friedrich* revealed some interesting peculiarities regarding the painter's representation of shadows and the light setting of the urban scene. The attempt to quantify and search for a specific time section in which the painter composed his representation led us to results that underline a significant discrepancy between digital reconstruction and pictorial representation. However, this has helped us to understand certain peculiarities in the representation of shadows in this artwork by Friedrich.

The analysis of the Figures 36-38 below suggests an important closing point: the different scenarios for each section of the watercolour analysed in this study are compared.

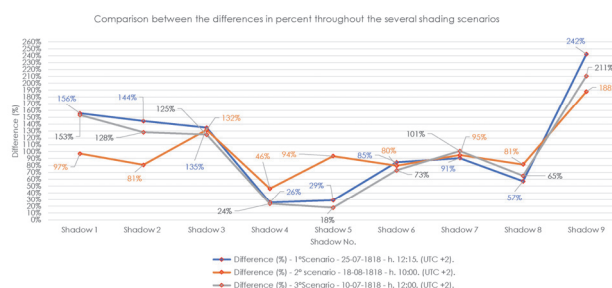


Figure 36: Comparison graph between scenarios for the Town Hall building: percentage differences for each remarkable shadow.

Looking at this graph, which considers the Town Hall analysis values, we realise that the shadows on the roof (shadows 1, 2 and 3) for the first and third July scenarios have a much greater difference than the second August scenario. Conversely, for these same scenarios, the shadows on the façade (4, 5, 6 and 8) match the watercolour much more closely.

The main hypothesis here is that we can identify a probable inconsistency in the representation of shadows on the same building, a hypothesis that could be further investigated by analysing further scenarios.

The summary graph of Building *Markt 1* (Figure 37) is much more complicated to read and analyse given the large differences between the different scenarios and with the watercolour itself.

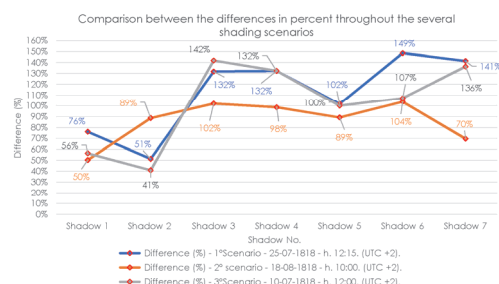


Figure 37: Comparison graph between scenarios for the Markt I building: percentage differences for each remarkable shadow.

From analysing these graphs, we can see that the values for this building are similar for certain shadows, but the percentage differences are so high that it is very difficult to identify a timespan that is more convenient than others. One factor to be emphasised that predominantly influences the shading of the scene compared to the 3D reconstruction is the difference in size (especially in width) between the building in the painting and the building in the historical 3D reconstruction. The building in the watercolour is significantly wider.

Finally, the analysis of the third section of the representation/model, i.e. the north side of the Market Square (Figure 38) leads us to realise how much the geometric difference due to the discrepancy in the representation of the buildings can impact this analysis. However, satisfactory values can be noted for shadow 1.

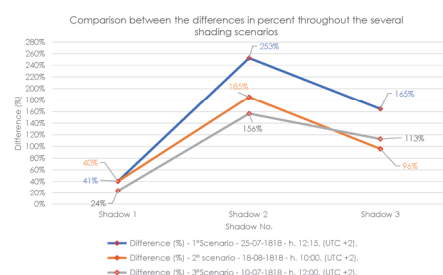


Figure 38: Comparison graph between scenarios for the northern side of the Market Square: percentage differences for each remarkable shadow.

In conclusion, considering the light scenarios analysed, it was not possible to obtain shadows that matched those of the watercolour in most cases. And considering the lower shadow difference values, one has to consider how the first and third scenarios in some of the shadows of the Town Hall achieved minimal difference values. On the other hand, we must consider that, while some sections had minimum values, others had values that were very different from those in the watercolour. Therefore, rather than identifying a precise time period in which the painting was created (an objective that could be achieved by analysing more scenarios), the study was concerned with showing how some of Friedrich's depiction methods could lead to the hypothesis of a mismatch between the shadows of certain parts of a building and those of another part of the same building, which seem to correspond to different scenarios at different times.

This type of study could therefore lead us to hypothesis that he wanted to replicate the lighting of the scene in his hometown, albeit inconsistently. This may be due to the transfer of the image of the market square onto paper; he did not intend to depict the shadows in slavish detail.

Using the shadow analysis workflow in Friedrich's representation allows us to make some observations:

1. Despite the quantitative differences, it should be noted that Friedrich depicted some of the shadows in great detail, and this can be seen in the 3D-modelled scene.
2. The artist's depictions of shadows in Greifswald are generally accurate. The trajectory of the light source in the 3D model reflects the shading observed in the painting.

## 8. Discussion – Limitations

### 8.1 Geometrical, detail and graphic representation differences

The analysis must take into account and list the differences between the reconstruction and comparison of the modelling of the square and Friedrich's painting, as these influence the analysis:

1. The number of elements represented, and the level of detail depicted by the painter, compared to the reconstruction of the buildings.
2. The size and measurements of the painted objects compared to those modelled in the reconstruction.
3. Any inaccuracies in Friedrich's representation of the length or inclination of the shadows will always lead to a certain degree of difference between the model and the painting.

These assumptions emphasise that, however accurate the painter may have been in representing the architectural elements, he still decided to eliminate, add or modify some of them as he wished. Such modifications obviously lead to differences in the shadows in the two representations.

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