

# SfM photogrammetric techniques applied in the building archaeology works of the old cloister of the Monastery of San Francisco from the 16<sup>th</sup> century (Cazalla de la Sierra, Seville)

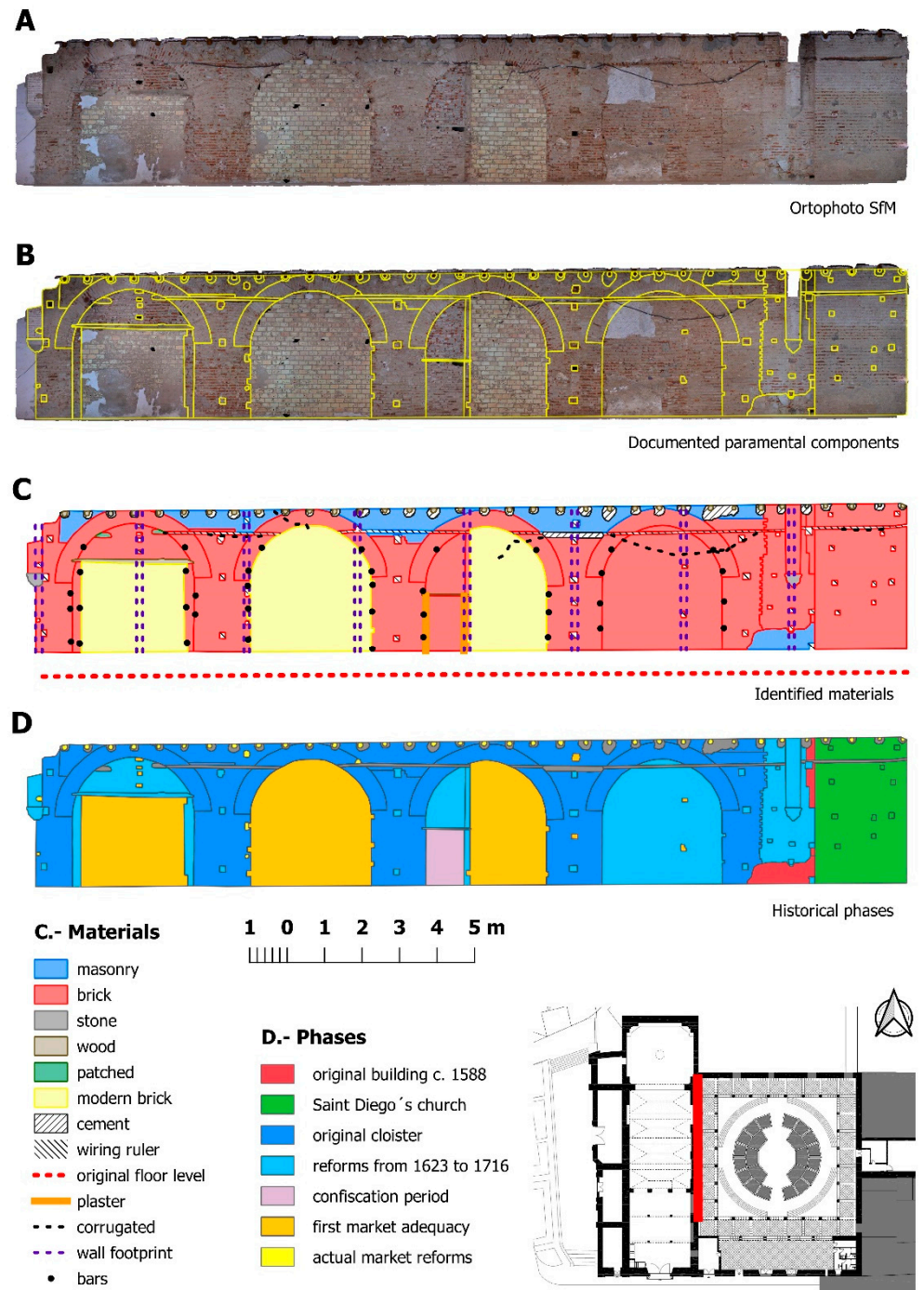
**Abstract:** The cloister from the old monastery of San Francisco (Cazalla de la Sierra, Seville) has been suffering a series of remodelling and transformations from its original construction, in the 16th century, to the current day. Thus, a study of building archaeology needed to be accomplished by using photogrammetric techniques by SfM (Structure from Motion) and laser scanning or TLS (Terrestrial Laser Scanning) that ensure a geometric exactitude and high resolution of the facings surveying. For that, over 500 images were taken for the 4 existing facings (about 78 lineal metres) from which a photogrammetric model was obtained of over 50 million polygons; as well as a cloud of over 40 million points from the laser scanning. It can be concluded that by using the techniques of SfM, the task of documenting, analysing and studying the facings of the historical buildings in order to establish its evolutionary process, gains, not only in precision and exactitude, but also opens the possibility to go further by obtaining products that are capable in the labour of conservation, restoration and protection of the historical heritage, as well as the generation of 3D virtualizations, planned for the diffusion.

**Keywords:** building archaeology; photogrammetry; SfM; heritage; restoration

## 1. Wall Face Analysis

### 1.1 Facing 1. W Face of the Cloister (figure S1)

The facing 1, or the W face of the cloister, serves as a party Wall with San Diego's Church, located immediately on the other side. In this sense, the transformation that this facing displays is related, not directly linked though, to the work of the church.



**Figure S1.** Wall face analysis from cloister's facing 1

### 1.1.1 Phase 1: Original building (first cloister)

The original remaining conserved of the first building constructed is circumscribed to the N extreme of the facing, almost completely hidden by a wall corresponding to the later church.

This is already the cloister of the primitive monastery, but with a different physiognomy and appearance to what can be seen today. It would have consisted of a completely open patio with a strong and austere appearance due to the simplicity of the walls and the

scarcity of openings, which would also be of little importance, both in size and ornamentation.

#### 1.1.2 Phase 2: Church and first cloister reform

It is possible that the face of the wall mentioned in the previous phase worked as an enveloping structure for the head of the church where a dome was developed that would require some kind of reinforcement on the perimeter walls of the church (figure S2). Almost certainly, behind this wall are the remains of the original building and probably a communication opening towards this sector, where there was either an earlier church or other monastery buildings. Perhaps this was the main reason for the reinforcement of the church facings in this area, as the existence of this previous opening could have provided less support for the church.



**Figure S2.** Detail of the facing of the church, the original wall and the reforms of the Cloister

In any case, the construction of the church reuses part of the W wall of the cloister and transforms the rest in a manner that creates a special solution of connection between that and the cloister itself.

Thus, the first reform of the cloister and the edification of the church should have been carried out at the same time. Based on the original building, the production of the church was completed so as to define the rectangle of its perimeter. A supporting wall was built in the N extreme in order to provide support to the church's head and the original facing of the cloister was almost completely reformed to open four semi-circular arches that allowed the vision between both spaces, protecting the access with grids of which the traces of their crimping have been left on the arches and the pillars between the these (figure S3).



**Figure S3.** Detail of the railings in the arches

#### 1.1.3 Phase 3: Final reform of the cloister

In this phase, the cloister suffers a series of reforms that provides the aspect it has nowadays.

In general, the porticoed gallery is built, for which the arches at the corners of the cloister have to be fitted into the original facings. In some cases, this fitting is very evident and has left significant traces, while in others it is more tenuous and barely noticeable.

As far as this facing is concerned, the arch at the S extreme fits perfectly into the wall of the arcade that connected the church to the cloister, while the one at the N end must completely replace the facing of the original building with a new facing of solid bricks, in order to have the right consistency to fit the arch and its corresponding bracket (figure S2).

In this phase of reforms, it was decided to close the arcades that paved the way for the intervisibility between the church and the cloister, building up facings of bricks in it, not all of them in the same way though.

From S to N the closure form was the following:

- The first arch is not completely closed, but only partially, making the visual gap between the two areas smaller and giving it a rectangular shape. This new gap was closed again by a new grille, the links of which are visible on the sides of the new facings.
- The second arch was completely closed. From the side of the cloister, this closure is not visible because the facing was located on the level of the side facing of the church; a small test pit in the wall of the existing contemporary bricks allowed us to see the closure on the other side.
- The third arch is partially closed. On the N half of the arch a facing was built and it flushed with the visible side from the church side. In the S half, a small connecting door is placed between the two areas and the upper part of it is closed up to the arcade.
- The last arch on the N extreme was completely closed, flushed with the new facing on the cloister's side (figure S3).

#### 1.1.4 Phases 5-6: Transformation for adaptation to the Market

In this facing the two moments of the Market are visible.

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The first consisted of a brick wall, probably of masonry, from the cloister facing to each column of the porticoed gallery. In the spaces left among quoits should have been located market stands.

These walls have left as evidence some putlog holes of the fitting of the new facings in the cloister, as well as the trace that draws its profile on the cloister facing.

From the second phase, it remains the fillings of the open putlog holes for the walls of the first market, as well as the hollow brick facing of all the arcades. In this way, a completely smooth surface was achieved, to which a layer of cement plaster and white paint was applied.

#### *1.2 Facing 2. N Face of the Cloister (figure S4)*

Facing 2, or the N face of the cloister, currently presents a physiognomy of a free-standing wall that separates the cloister from a patio belonging to the schnapps factory located nowadays into the original block of the cloister, in its N part; although it was not always this way (figure S5).

The reforms and the transformations of this facing are related mainly to the mentioned above on facing 1, regarding the adequacy of the cloister to its current physiognomy, as well as the performance carried out mainly in the 19<sup>th</sup> century, probably linked to the schnapps factory mentioned before.



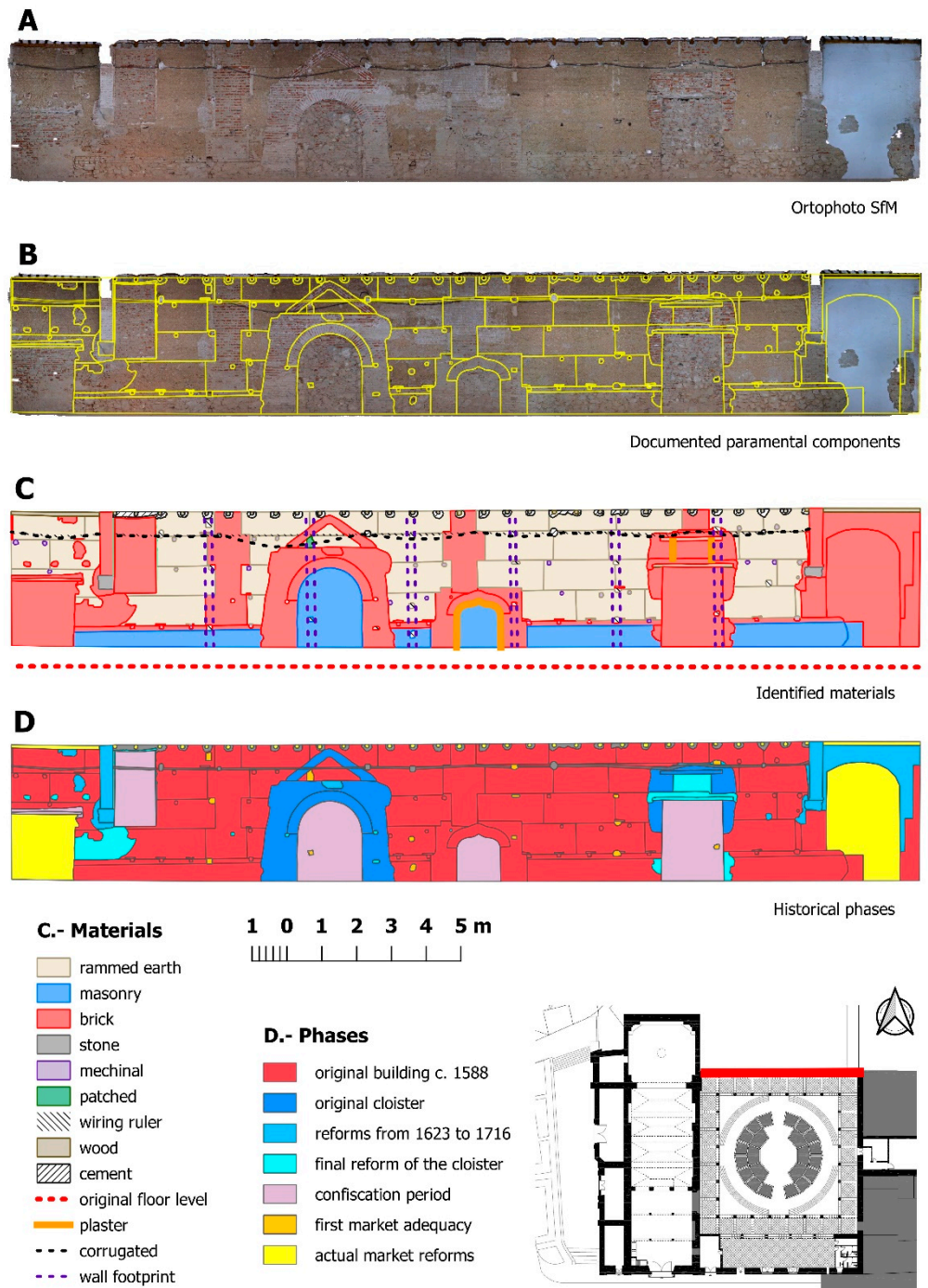


Figure S4. Wall face analysis from cloister's facing 2



**Figure S5.** Footprint on the head of the church on the second floor of the corridor that existed to the N of facing 2. (Carlos García Corral (2010): 18 viviendas en el Corralón del Convento de San Francisco en Cazalla de la Sierra)

#### 1.2.1 Phase 1: Original building (first cloister)

In this facing, the original remaining of the first building occupies that total practice of this, although with some modifications that in some cases belong to the cloister life while it had that function.

From all the hollows that can be observed in the facing, just one is originally from this phase. This is the small ogee-arched doorway, framed by a brick spandrel and located exactly in the centre of the facing (figure S6).



**Figure S6.** Main door of the original cloister with an ogee arch on the top

Possibly this door, special in its physiognomy, gave way either to a noble dependency of the monastery, or perhaps to the original chapel in which the monks of the monastery celebrated their liturgical acts before the construction of the church, which, as we have seen in the description of the previous facing, did not take place in the original construction of the monastery, but in a second phase.

Moreover, in this facing, we can clearly observe the building typology of the monastery's original walls (figure S7).



**Figure S7.** Original factory on facing 2

This is a masonry plinth made of medium-sized stones, framed at the top by a brick wall made up of a double row. The function of this plinth is to insulate against dampness, making it difficult for water to rise to the upper part of the facing.

On this plinth, there are up to four rows of improved rammed-earth walling caissons of variable width depending on the needs of each wall, separated by strings of brick blocks whose function is to reinforce the facing at certain distances between the walling caissons. The height of the caissons varies between 0.84 and 0.87 metres and their standard width varies between 1.95 and 2.00 metres (there are smaller caissons depending on the distance available to fit the blocks). The spires of the caissons are not topped with any brick or stone (except in very isolated and punctual cases), and in a notable number of cases, the caissons are outlined with a fine line of lime and a thin line of stone.

This type of walling covers a possible chronology with a fairly broad spectrum, ranging from the 12<sup>th</sup> century to the 18<sup>th</sup> century, but if we take into account its main characteristics [43], moderate invasion of the chaining on the walling caissons, non-existent brickwork that is limited to the separation between the plinth and the walls, and very evident lines of marking and separation between caissons, the date of the 16<sup>th</sup> century fits perfectly to consider it as the date of its construction. This date, therefore, is in line with the other known chronologies for the entire building complex: the church was started to be built after the cloister was built and work began circa 1623, while the convent was built circa 1588 at the latest.

This facing shows another very interesting feature. It is the original floor of the cloister. It is clear that the one that exists today is not; indeed, it can be affirmed that it was not at any time during the life of the cloister as such. Thanks to the view offered by the back of this wall, and by georeferencing a photograph taken of it on the ortho-photo obtained by photogrammetric methods for this work, it can be established that the original pavement is approximately 0.60 metres below the current one (figure S8). This would explain why there could be a doorway in this facing with a span of only 1.36 metres in height, since when these 0.60 metres are added together, it would be almost 2 metres, enough to facilitate the passage through it.





**Figure S8.** North facing 2, with the elements of the south face, georeferenced and indicating the original floor level of the cloister

#### 1.2.2 Phase 2: First cloister reform

Coinciding with the construction of the church, the cloister suffers the first of the two great alterations that it was to suffer during its life as a cloister. In facing 1, we can see how four large semi-circular arcades were opened to visually connect the church with the cloister.

In facing 2, two hollows will be opened in addition to the existing one. The first of these is a new door in the W half of what is supposed to have been the monastery chapel. This chapel probably lost its function as such when the church was built and its use changed, although it must have had a certain singularity in monastic life due to the size of the new access door. This was built with a large round arch, framed in a brick spandrel, and was finished off with what was probably a pediment that must have protruded slightly from the wall and of which the part that was embedded in the original facing is still preserved. (figure S9).



**Figure S9.** Detail of the front and the semicircular arch of the new open portal on facing 2

At the same time, a window was opened in the E half of the wall, also framed by a brick spandrel, which must have served to provide better lighting for the new activities taking place in the room behind it.

### 1.2.3 Phase 3: Final cloister reform

In this phase, the cloister suffers a series of reforms that give it the aspect it displays nowadays. On facing 2, two corner arches of the new porticoed gallery of the cloister are placed, which must partially replace the existing mud wall with a reinforcement of solid bricks that help to give consistency to the arch and its corresponding bracket in the wall. The artistic quality of this corbel is noteworthy, as it shows a human head in relief in which all its parts are perfectly distinguishable (figure S10).



**Figure S10.** Corbel in the shape of a human head from an arch in the porticoed gallery on facing 2

On the E extreme of the facing, a new large dimension hollow is opened. Its construction is a bit rare since it looks as if it would have liked to be ended with a semi-circular arch of a bigger radius than its door, thus it is abnormally aborted at its W extreme. From the typology of the hollow and its dimensions, it must have served as a passageway to the N side of the buildings annexed to the cloister where there was a free area dedicated, in the part closest to the buildings, to gardens and orchards.

Moreover, the opening of two more hollows can be observed. The first one is located on the W half of the facing, immediately after the arch of the porticoed gallery. It is a big proportion window. The second hollow is a doorway on the E half of the wall, between the original door of the building of the cloister and the new one opened in this phase. The size of that doorway is significant, even closing the previously opened window.

Probably, these new reforms are linked with a new inner compartmentation of the surroundings of the cloister, whose function is unknown yet, and that required form the opening of several hollows, especially doors, towards the cloister. In the analysis of facing 3, this phenomenon can be appreciated with the same intensity.

### 1.2.4 Phase 4: Reforms during the Spanish Confiscation

In this phase, a new hollow is opened on the W extreme of the facing which consists of a quite wide door.

At the same time, three of the four doors that had existed up to that time were closed, respecting the one furthest to the E, and the window opened in the final section of the



previous phase was also closed. This way, the facing is left completely smooth with two doors of some importance at the ends.

All these reforms are probably related to the establishment of the anisette factory around 1870 inside the convent block, which among other transformations demolished the entire part of the existing building to the N of this facing 2, leaving it as a free-standing wall separating the cloister from a large open area to the rear. The two doors at either end may have made sense in order to communicate the two spaces, bearing in mind that the anisette factory also made use of the monastery's installations, including the church.

#### 1.2.5 Phases 5-6: Transformation for the adequacy of the Market

The two moments of the Market are also visible on this facing, which was caused by the same reasons as those described for facing 1, and left the same evidence and traces on the facing (figure S11).



**Figure S11.** Imprint of the market walls, drawn on the wall of the cloister

Another important reform that is done in this phase is the one of the surveying of the cloister floor to the current level. It has been possible to document how all the hollows that were closed prior to this phase re-pass the current floor level until they reach what must have been the original one, while the hollows that were closed with the adaptation of the market reach the current floor level. This allows us to conclude that the floor underwent a rise in level to that which currently exists in the phase of adaptation of the cloister as a marketplace, as we have described in phase 1 of this facing.

#### 1.3 Facing 3. E face of the cloister (figure S12)

The facing 3, or E face of the cloister, is the one that has suffered a bigger account of reforms and modifications from its original construction.

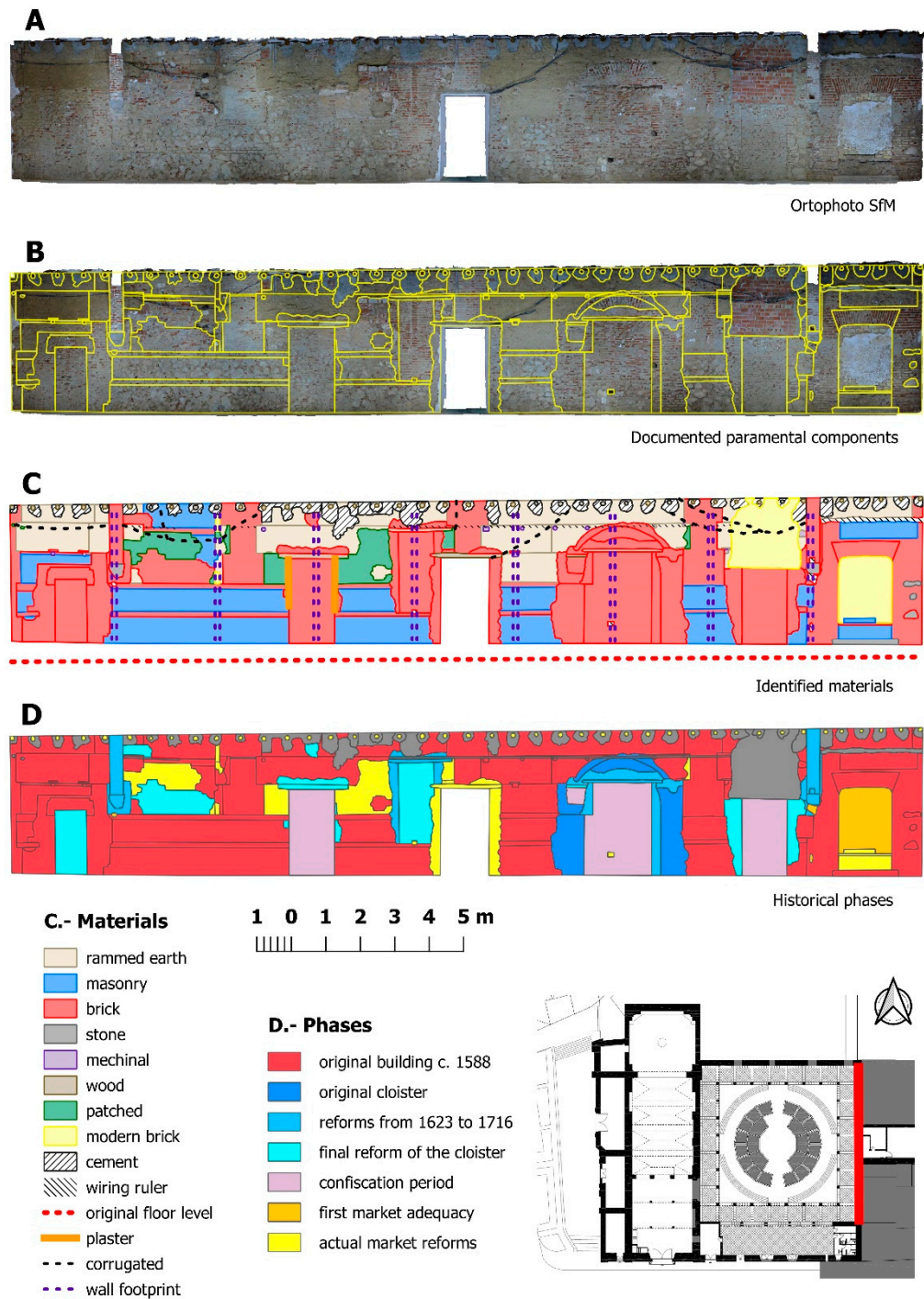


Figure S12. Wall face analysis from cloister's facing 3

1.3.1 Phase 1: Original building (first cloister)

In this facing, the original remains of the first building constructed occupy practically the entirety of the building, except for the many hollows that were opened and closed during the overall life of the building, to which must be added a significant amount of brick patching to repair and improve the deterioration that occurred in it.



Two original hollows from this phase have survived, each located at either extreme of the wall. The first, to the N of the facing, is a small doorway whose lintel has been greatly modified, and we cannot determine its actual configuration. The other hollow, to the S of the facing, is another doorway, this time of more significant dimensions and with a brick lintel arranged in such a way that it resembles a segmental arch. Both doors are framed by a brick lintel.

This facing shows the same original building typology of the monastery that we have already seen in facing 2. It is a masonry plinth made of medium-sized stones, framed at the top by a double course of bricks. In this case, the plinth is higher than that of facing 2, as a second section of masonry is placed on top of the finishing string course at the bottom of the plinth, which is again finished off by another double course string course. In turn, above the two doors of this facing, there is a new band of masonry on the upper lintel, this time topped by a simple single course of bricks. Possibly this extra band of masonry had a more aesthetic function than that of aiding the stability and robustness of the facing. (figure S13).



**Figure S13.** Detail of the masonry plinth and rammed earth wall of facing 3 of the original building

Unusually for this type of rammed-earth building with a masonry plinth, there is a small section, between the first door to the N and the first brick wall, in which two new sections of masonry can be seen, separated by a double brick facing, which reaches the edge of the roof. It is difficult to say more about this because these sections of masonry are covered, over a considerable area, by patches of bricks of different types and dates, which are repairing faults in the construction of the facing.

Returning to the original masonry of the facing, on the plinth, there are up to three rows of rammed earth boxes of variable width ranging between 0.80 and 0.85 metres in height and between 1.95 and 2.10 metres in width. The typology of the rammed earth has the same characteristics as those of facing 2, thus the discussion we made about its possible chronology is equally valid.

To conclude this phase, we must highlight an important aspect of the door located to the S of the facing. It is the existence of a step with a tread height of between 0.18 and 0.20 metres. Bearing in mind that the floor in this place would be between 0.40 and 0.60 metres lower, it is highly probable that there are two or three more steps. All in all, this span makes sense in that it is the start of a staircase leading to the upper floor of the building attached to this wall on its E side (figure S14).



**Figure S14.** Start of the staircase indoor S of facing 3

### 1.3.2 Phase 2: First cloister reform

In this facing, the first reform that the cloister suffers in tune with the edification of San Diego's Church consists of the opening of two new hollows on the wall, conserving both that already existed on its extremes of the previous phase.

One of them is an access doorway in the S half, larger than the one that opened in facing 2. This too is formed by a semi-circular arch and is framed by a brick spandrel. The building on the other side of the facing must also have been, as we said in the case of facing 2, of great singularity and importance for monastic life, considering the size of this doorway. At the same time, a window was opened almost in the middle of the facing.

### 1.3.3 Phase 3: Final cloister reform

Just as the two arches at the corners of the new porticoed gallery of the cloister were placed in facings 1 and 2, so too in this third one, with the same construction and characteristics.

The doorway of notable dimensions, opened in the previous phase, underwent a small alteration that slightly reduced its width and replaced the upper semi-circular arch with a straight wooden lintel. In the upper left corner of the new doorway, there is a small square opening (figure S15), which may have been a small niche.



**Figure S15.** Start of the staircase indoor S of facing 3

The window opened at the beginning of the cloister reforms was closed in this phase, as was the doorway reminiscent of the initial phase, located at the N extreme of the wall.

At the same time, two new doors were opened, smaller in width but of a certain height, which must have served to access the existing building, which must have been compartmentalised inside at this time, perhaps with an added change of function.

#### 1.3.4 Phase 4: Reforms during the Spanish Confiscation period

In this phase, all the hollows were closed except the one located on the extreme 5 and that had the staircase to the upper floor.

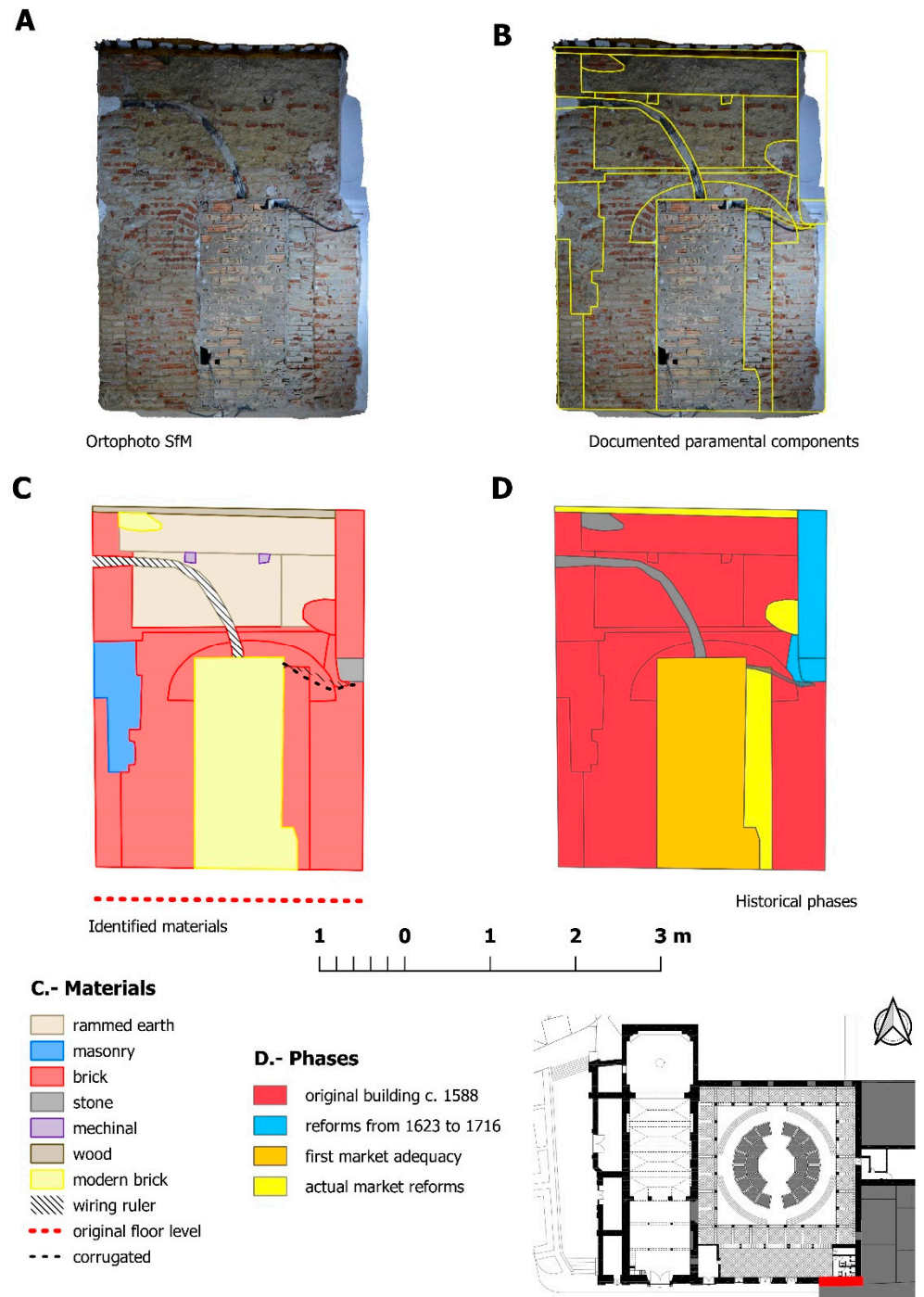
#### 1.3.5 Phases 5-6: Transformation for the adequacy of the Market

The reforms and traces preserved from the adequacy of the space to the market are exactly the same as those mentioned for facings 1 and 2.

Two other traces remain of the alterations made to adapt the space for the market: multiple brick patches to repair parts of the facing that had deteriorated, and the opening of a door in the centre of the wall to give access to the market rooms that were located inside the annexe.

#### 1.4 Facing 4. S face of the cloister (figure S16)

The facing 4, or S face of the cloister, is small in size, so the number of documented elements is small. Nevertheless, it is very interesting from the point of view of the original building.



**Figure S16.** Wall face analysis from cloister's facing 4

#### 1.4.1 Phase 1: Original building (first cloister)

In this facing, almost all of the preserved remains are original from the original cloister.

There is a hollow corresponding to a door, which has a bell-shaped arch in the upper lintel. It is framed by a brick spandrel like all the doors of the original building and all the hollows opened in the first cloister reform (figure S17).





**Figure S17.** Detail of the factory of facing 4 of the original building; and basket-handle arch of the door of this facing

The original masonry in this facing is very much obscured by the limited space available to document it, considering that most of the space is occupied by the hollow and its spandrel. However, on the E side, there is a brick wall and on the upper part of the wall, there are the mud-brick caissons that form the base of the facing. There is a small space between the door's spandrel and the buttress in which the masonry that also forms the building typology of the original building can be seen.

#### 1.4.2 Phase 2: First cloister reform

No evidence of the first reform of the cloister can be detected.

#### 1.4.3 Phase 3: Final cloister reform

From the final reform of the cloister, the arch of the porticoed gallery can be seen, and the improvement of the original facing in the area of the corbel of the cloister can be seen.

#### 1.4.4 Phase 4: Reforms during the Spanish Confiscation period

No evidence can be detected in this phase.

#### 1.4.5 Phases 5-6: Transformation for the adequacy of the Market

The existing door of the market was closed to bring it into line with its current appearance.