



OUR TOWN HALL
MANCHESTER CITY COUNCIL

TERRIX PLASTER REPORT

OTH-PUR-XX-XX-RPT-A-0166
FOR INFORMATION
REV 02
21/12/2021

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Issue Details

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Terrix Plaster Report	-	INFORMATION	15/12/2021	JC
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A. Technical justification and heritage impact analysis

Introduction:

The following is intended as a short justification document for the use of 'Terrix' plaster as an alternative to the current replacement plaster specification. The process for assessment follows the agreed process for OTH as set out in OTH-PUR-XX-XXRPT-A-0007.

An assessment of impact measures the identified levels of significance against the degree of change proposed, and whether this causes harm. Harm to heritage significance should be avoided. If this is not possible, the second test is to ensure that the harm is necessary, and thirdly, that the harm can be clearly and convincingly justified. Justification relies on the balance between harm and benefit. The benefits of a proposal must be in the public interest.

Prior to carrying out this process, it is essential for the significance of the affected area and/or element(s) to be fully understood. Once significance is fully understood, the process for assessing the impact of change can be carried out by testing against five key questions:

01 What is the level of change?

02 What is the potential impact of change?

03 What is the need for change?

04 Can harmful change be mitigated?

05 Can harm be justified against public benefit?

01 What is the level of change?

The change only applies to areas in spaces to be refurbished where a proportion of the existing plaster on flat wall surfaces has been removed as it was found to have been defective or had delaminated from the masonry. The areas affected by the change are the non-VHS (very high significance) rather than those to be restored, but as these defective areas are widespread, much of the back-of-house spaces of the site will be affected. However, the plastered surfaces in very high significance spaces to be restored and any decorative or moulded plaster are not to be included within this proposal, and any repairs or replacement in these areas will continue to be carried out in traditional 3 coat lime hair plaster as currently specified.

02 What is the potential impact of change?

The proposal is to use a non-traditional method for the application of a modified potassium silicate and hydraulic dolomitic lime based plaster to these walls where defective plaster has been removed. There is some potential harm to significance caused by not continuing a like-for-like approach to using traditional methods of application, although this is largely theoretically and relatively modest. Visually the plasterwork will not be noticeably different to the original 1870s plaster, or the current replacement specification, to an observer. More importantly, it has been acknowledged that the original lime plaster that has delaminated, failed immediately after application in the 1870s, as it cracked and delaminated when applied to the brickwork due to excessive suction and the volatile nature of the pozzolan mix. On removal of the failed wall plaster it was evident that there had been very little, if any, adhesion of the plaster to the brickwork as there was no residue of plaster stuck to the masonry surface. The poor appearance of the defective plasterwork was harming the aesthetic values of the Town Hall and the sheer scale of the inherent defect in the original plaster is such that reapplication of using a like-for-like specification is not an option as it would certainly risk a reoccurrence of the same failed result. Therefore, with regards the visual appearance of the spaces within the building and the performance of the plaster long term, the use of a system that will ensure that the defect will not reoccur, and achieves a better result, can potentially enhance significance.



Areas of existing delaminated plaster removed from wall leaving no residue on the brickwork (note the original limewashed lines showing the route of the flues are still clearly distinct)

03 What is the need for change?

As previously discussed, where the original 1870s plaster failed, it appeared to fail on application and a 'like-for-like' approach to replacement would likely mean a similar result.

Whilst there are large areas that had adhered and have survived there seems to be no pattern to where it was successful or where it failed that relates to subsequent overpaint or environmental changes. The Hirst report took samples from various places across the site, and they undertook the same analysis on each sample. The results showed that the original plaster mix was very varied and unpredictable. Wherever the plaster failed there was no residue left on the brickwork which indicates that it was an initial defect, not a progressive failure. It appears, therefore, that the defective areas are where a combination of initial workmanship and material factors meant that the plaster failed immediately it was applied. Factors such as imprecise batching of materials with a lack of binder or uncontrolled impurities, leading to a chemical set that was either too fast or unstable meant that it didn't adhere. This could have been combined with a substrate that was too dry affecting suction rates, along with disparate amounts of hair or fibre in the mix to control shrinkage. It is clear from the analysis that generally the ceiling and moulding plaster, and the stateroom wall plaster, utilised better quality materials, more tried and tested mix technology and was better controlled in mixing methodology and application workmanship which explains why there is much less failure in those areas.

The Hirst analysis and report predated the Purcell survey that identified the delaminated areas of plaster. The Hirst analysis demonstrated that the plaster mix varied greatly but (apart from establishing that the moulded run plaster, and the plain plaster in the state rooms is better quality generally) it didn't correlate a particular mix or application scenario with an area of delamination. For this reason, it will be extremely complex to define what actually caused an area to fail and equally what helped an area to adhere successfully, and consequently what mix and methodology would need to be avoided or conversely replicated. For this reason, it would be very risky to attempt to repeat a particular approach based upon analysis of the original plaster even though we will, of course, be ensuring to mitigate some of the possible causes of failure such as excessive suction due to the substrate being too dry prior to application when we reinstate.

The failing plasterwork needs to be remedied to mitigate any risk of reoccurrence and avoid a poor-quality appearance and defective plasterwork as a finish for the building, which is not deemed appropriate or acceptable given the heritage significance and grade one listing.

The original 1870s plaster is not a 'traditional' non-hydraulic lime plaster. From the analysis carried out by Hirst Conservation in 2019 as part of Purcell's initial investigations it was clear that Alfred Waterhouse had chosen a complex 'hot lime' mix consisting of a Dolomitic (magnesian) limestone binder which provides a moderately hydraulic chemical set reaction but is slow to calcify. There is also a volatile mix of pozzolanic aggregates such as blast furnace iron slag, pulverised coke fuel ash and brick dust mixed in with river sand and clinker. This gives the base coats a characteristic mid to dark grey colour. The plaster coats were also gauged with gypsum to provide an enhanced set which added to the complicated chemical reactions and salt action that were already a consequence

of all the other active ingredients being mixed together. The consequence of this highly complex chemical stew, along with a rapid suction that happened when applied to the wall, is that the plaster may have set too fast and dried out before calcifying properly. The analysis also found that there was a paucity of hair or other fibrous material in the plaster base coats which exacerbates the failure of the coating. Impurities and salts within the mix may have also expanded during the set (or caused a phenomenon called thaumasite and ettringite sulphate attack) pushing the plaster off the wall surface in large areas. This would explain the lack of adhesion and lack of residue left on the surface where the failed plaster has been removed.

Purcell initially specified using a traditional (non-hydraulic) 3 coat 'fat' lime putty, sand, and hair plaster with a gauging of gypsum as a repair plaster prior to having carried out a full 'tap' test of the wall surfaces. This was not a like-for-like replacement for the original as demonstrated by the description above. Due to the surprisingly large proportion of defective original plaster that has been found in the refurbishment areas of the project, and the result of the mock-up room trials, the use of the current specification for the replacement of the defective original plaster in all the refurbishment areas will be too challenging, as it requires a great deal of tending to avoid shrinkage and is extremely difficult to butt up to the retained areas of the original without further loss of the historic finishes. Concern has also been raised about the durability and benefit of using the traditional plaster in a heavily occupied back-of-house utilitarian office environment as compared to the highly decorative very high significant public spaces. It was therefore agreed to investigate alternative 'refurbishment' specifications that would be more compatible to the density of the brickwork substate, be more durable in use, be permeable to water vapour without deterioration and sulphate attack and be applied in a method that allowed retention of selected areas of original plaster and the associated joinery in situ, whilst enhancing the overall appearance of the spaces.

The Terrix materials are based upon a hydraulic Dolomitic lime binder which is similar to the original plaster but doesn't contain all the pozzolanic impurities found in the original mix. The aggregate in the Terrix RD-LG restoration base coat plaster is a polymer of potassium silicate mineral that is the basis of many vapour permeable renders and paints used widely on listed buildings. It is also reinforced with a micro fibre which is similar to the use of hair in traditional plasters. The base coat is mixed in a machine off site, applied by a render pump and then trowelled on. The site trial has shown that this is an extremely clean and sympathetic process which is appropriate for a heritage interior, enabling all the existing joinery to be retained in situ and requiring limited protection of adjacent finishes. The finishing has proved to be similarly manageable and additional trials have demonstrated that the top coating system can successfully overcoat the remaining original finishes with a vapour permeable layer of plaster once a 40% removal of impermeable paint has been achieved mechanically. This has the dual benefit of reinstating a vapour permeable surface to areas that have been overpainted with multiple layers of impermeable modern plastic paints and also reinstates a smooth surface finish to areas with disfiguring wear and tear surface damage.

A detailed specification for this alternative proposed system is in preparation and will be forwarded when complete and verified.

Key benefits from the use of the proposed system include –

- Product adheres to the substrate and provides a consistent bond, which the original product has not (there are numerous examples of failure and delamination of existing plaster across the building).
- Product is breathable and suitable for use on historic buildings.
- Reduced drying times and less shrinkage giving programme and quality control benefits.
- Greater flexibility in terms of material depth to overcome the existing wall tolerances i.e. The mock-up room required a nominal 45mm thickness which can be achieved with two base coats of Terrix. However, traditional lime plaster would require three base coats.
- Over coating of existing walls is feasible and would require scarifying to remove 40% of modern acrylic paint layers which provides the added benefit of reinstating the breathability to retained plaster thus removing an existing major defect.
- Over spraying would deliver a higher quality of finish which is appropriate to the listed interior.
- The finish is easily repairable in the future with a readily available product enhancing the future maintenance.
- Utilised in Europe on equivalent heritage projects for 15 years
- Still using traditional skilled labour and traditional materials for very high significance spaces and decorative plaster
- Cleaner application technique and it allows for better protection of existing features.
- It is significantly more efficient and cost effective to apply which will enable a full refurbishment benefit to be achieved.

04 Can harmful change be mitigated?

It was not possible to mitigate wholesale renewal of the identified delaminated areas as the chosen rectification of the defect in the original plaster. The failed plaster could not be repaired in situ as the risk of progressive cracking and falling off in sheets if it was retained was considered too high. We have identified significant areas of original plaster that is well enough adhered to retain in situ which preserves the historic evidence of the original on approximately 60 to 70 % of the wall area in the refurbishment spaces. A much greater proportion is retained on the ceilings, mouldings and on VHS restoration space walls. We have recorded the plaster base coat and finish in several areas of the site which is included in the Hirst report of 2019 appended. There is also a comprehensive record of the paint schemes in selected areas contained within the sampling reports from 2019 and 2015 to mitigate the loss of evidence on the defective plaster removed.

In terms of why the renewal of the plaster in an exact like-for-like manner has not been proposed, we have justified the change in specification necessary above to mitigate a reoccurrence of the defects. However, we suggest that the proposed choice of the Terrix product as a replacement wall plaster in the back-of-house areas is very similar in principle to the original design intent, in that it is a hydraulic dolomitic lime binder with a polymeric mineral silicate aggregate. The change is just that we are proposing a much more scientifically designed and quality-controlled mix, produced in a factory rather than on site. Other than the manufacture the main change is that the mineral aggregate is potassium silicate based rather than a reactive hotch-potch of river sand, iron slag, fuel ash and brick dust, and the application method being by pump and spray rather than by darby float and trowel.

To reiterate, it is still proposed to use a traditional method of lime plaster application in the very high significance spaces and any ceiling and moulded feature repairs as these areas had a superior specification previously. The proposed alternative approach still uses a breathable lime-based plaster ensuring vapour permeability for the building in the long term. However, the use of a like-for-like replacement of the original is not practical in the refurbishment areas, and a traditional lime plaster would represent a greater change in material from the original in those areas anyway. The sheer amount of renewal of defective wall plaster (some 30 to 40 %) means that traditional methods of application would not be feasible. There is no appreciable difference to the final appearance caused by the change in application as proved by the site trial.

05 Can harm be justified against public benefit?

As previously discussed, in many ways the approach can be considered beneficial to significance as, if it is a choice between replicating a failed system or changing to an alternative innovative approach that allows the aesthetic values of the spaces to be maintained (and enhanced) then the use of Terrix is not considered harmful. However, it is acknowledged that the approach of using an alternative to that used by Waterhouse in the 19th century and not using a traditional technique of application for the back-of-house flat wall areas does constitute some low-level harm, but justifiable due to the scale of the defect to be rectified and the inherent technical issues with the original specification. The public benefits are numerous including those outlined above such as a proven technical solution to an inherent defect that retains vapour permeability, quality control, longevity, and enhancement of the visual amenity of the spaces, through the better application to the substrate and rectifying surface damages, cost and programming benefits ensuring value for money and complete refurbishment coverage, cleaner application and being more easily repairable.

B. Options summary and recommendation

It should first be noted that some options have already been dismissed as being inappropriate from heritage, aesthetic, and fitness of purpose aspects. These include removal of defective plaster and stabilising the brickwork (although this is being adopted where walls are concealed within lift shafts, risers or other boxing out) or dry-lining with plasterboard and skim on dabs. Having decided that, where walls are not concealed from view, a full thickness of plaster should be reinstated to original profiles on the existing brickwork there are three suitable options for consideration as follows:

Option 1: Like-for-like renewal: The original plaster applied to the building in 1875 failed immediately. This is evident in the cracking, debonding and falling off of the original plaster from the brickwork walls. It is likely that it failed because of the complexity of the chemical reaction in the mix and the premature drying out due to a combination of material and workmanship issues. It would be unacceptable to repeat the mistakes of the past with the inherent risk of failure as this would be harmful to the heritage significance and lose an opportunity to benefit from the rectification of the defect and enhancement of the aesthetic appearance. Refer to section A-03 above for a detailed description of the risk issues and the potential impact upon the heritage significance with this option if the replacement plaster fails or deteriorates more rapidly than expected. These risks and impacts easily outweigh any heritage benefit gained from attempting to archaeologically replicate the original methodology. The traditional application methods does carry a moderate risk of damage to surrounding fabric which would consequently require significant protection measures to mitigate

this risk and would also require temporary removal and reinstatement of original adjacent joinery features to facilitate a satisfactory quality of trowelled finish.

Option 2: Replicate the original plaster specification as near as possible whilst rectifying the workmanship and material defects: The issue with this option is that the original specification varied so much that it would be difficult to decide upon a suitable compromise mix. Refer to section A-03 above to again understand the risks with attempting to replicate the original methodology whilst improving or enhancing the original to mitigate some of the causes of failure. The basic intent of the original plaster appears to be using a hydraulic dolomitic lime binder with a polymeric mineral silicate aggregate. The challenge in this option would be to find a reliable, well-trying mix that complied with this principle and apply it more carefully with the correct surface preparation. Having investigated the available products we conclude that there are moderately hydraulic lime mixes available that comply with this requirement including the Terrix products, and they could be applied in a traditional method whilst overcoming some of the original potential workmanship mistakes relating to excessive suction in the substrate and lack of control of shrinkage and expansion. However, as with option 1 above, these methods of application would require much more protection, removal and reinstatement of existing joinery, more complex tending, more coats with longer curing times to achieve a satisfactory finish.

Option 3: Use of the proposed Terrix product and using the pump and spray application method: The change with this option over option 2 is minimal. Terrix is essentially a similar mix to the original in that it is a hydraulic dolomitic lime binder with a polymeric mineral silicate aggregate containing minerals that provide a chemical set. The change is just that we are proposing a much more scientifically designed and quality-controlled mix, produced in a factory rather than on site. Other than the manufacture the main change is that the mineral aggregate is a sophisticated yet naturally permeable potassium silicate based polymer rather than a reactive hotch-potch of river sand, iron slag, fuel ash and brick dust, and the application method being by pump and spray rather than by darby float and trowel. The Terrix plaster proposal meets key criteria for the new plaster specification in that it is lime-based and breathable, and also allows the reinstatement of a permeable finish to be applied over the remaining impermeable paint surfaces. This ensures that the maximum quantity of the original plaster that is stable can be retained and enhanced in both aesthetic appearance and performance. Terrix will match the appearance of the existing plaster but will provide a more consistent, long-lasting finish for the building. In addition, it can be pump and spray applied which minimises mess, damage, need for protection and risk to operatives. The pump and spray application therefore significantly reduces the impact upon the heritage as it reduces the risk of damage to surrounding fabric due to the cleanliness and control of the application, avoids the need, therefore, for any major protection measures generally and particularly has the significant benefit of not having to remove and reinstate any adjacent original joinery or fittings which preserves its heritage integrity. It also offers significant programme advantages both in application but also curing timescales which reduces budgetary pressure which ultimately benefits the project aim to protect and enhance the highly significant heritage of Manchester Town Hall for the public good.

Recommendation: We recommend option 3 as it is a sympathetic and appropriate solution to a specific and inherent historical challenge at the Town Hall. It allows the retention and enhancement

of the maximum amount of the original sound plaster whilst solving the particular set of defect issues that relate to the problematic areas. This proposal should not therefore set a precedent for all listed buildings in the city as it is not considered possible to replace the original inherently defective plaster on a like-for-like basis, but it does offer a practical and technically innovative remedy to an extremely unique set of heritage circumstances. One of the objectives of the OTH project and a historical tradition in Manchester is to use innovation to overcome a particular challenge or enhance an opportunity. Alfred Waterhouse would applaud this approach.



Aggregate in existing plaster mag.x10 from Hirst report 2019 showing the highly complex mix of aggregates and impurities

END

Appendices attached



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BUILDING AND
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TERRIX[®]
renovations

Terrix[®] renovations listed buildings photo gallery

V.1.0.G 2019/11

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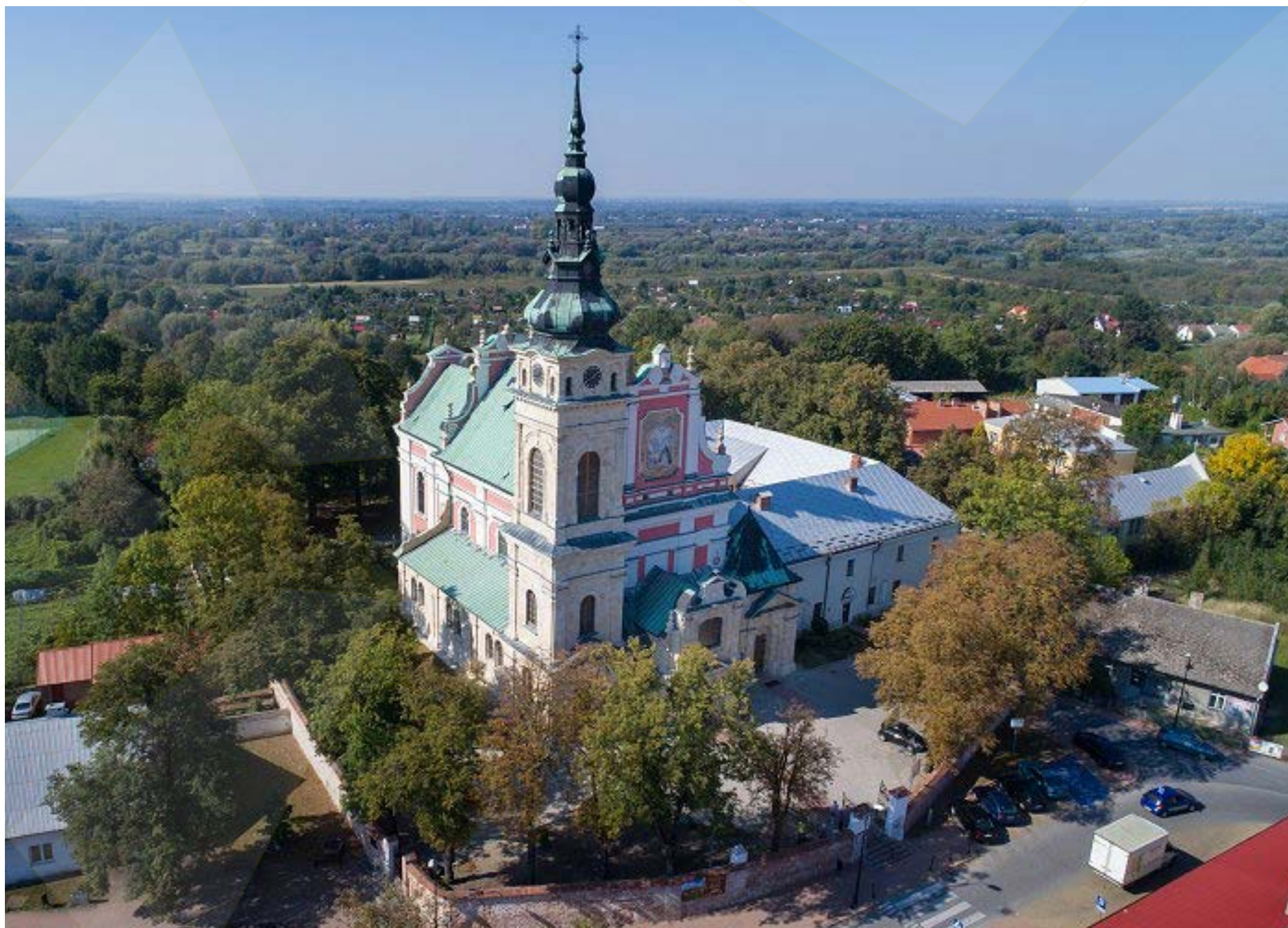
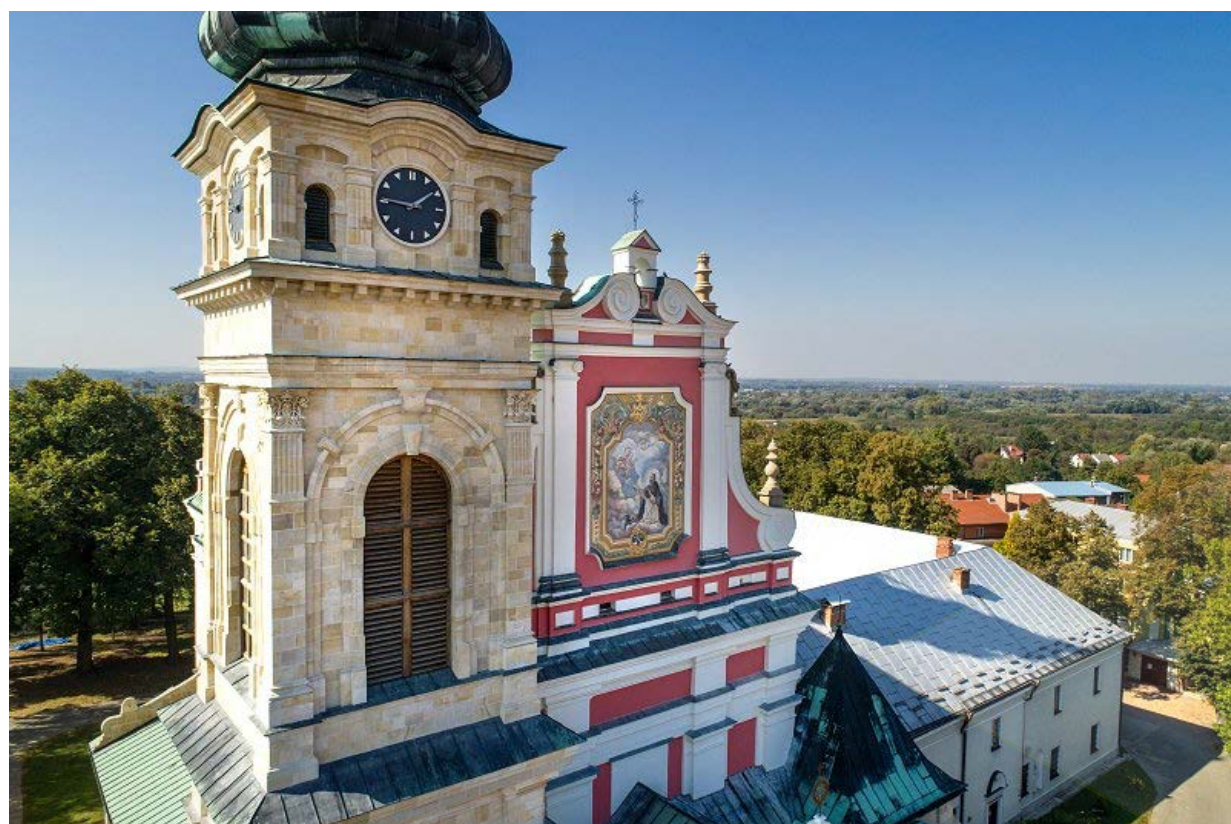
Church - Kortynica Laskorzewska, Poland

products used: silicate based renders and paints



Monastery - Tarnobrzeg, Poland

products used: polymer-silicate based renders and paints



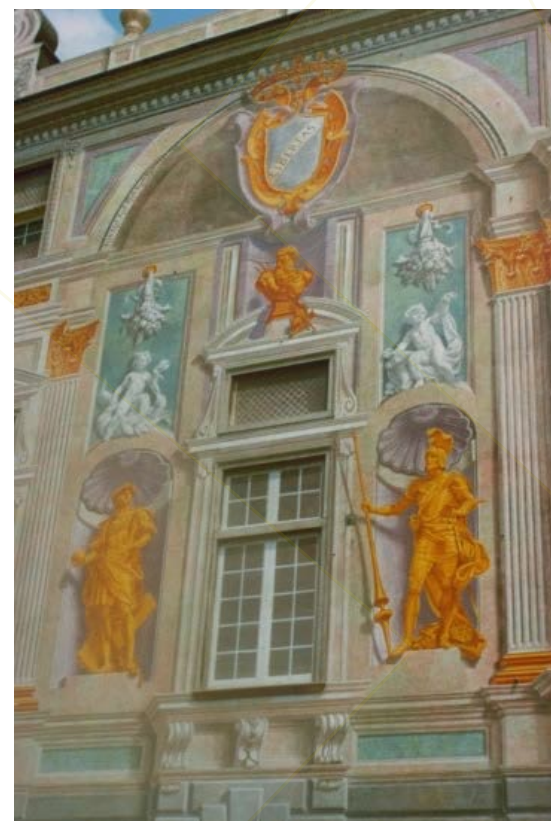
Cathedral - Siedlce, Poland

products used: polymer-silicate based paints, lime fillers and plasters



Other - Europe, various locations

products used: various



Episcopal Curia - Wroclaw, Poland

products used: polymer-silicate based renders and paints



King Jan III's Palace at Wilanów, Poland

products used: polymer-silicate based renders and paints, lime plasters and fillers



Czapski Palace - Warsaw, Poland

products used: polymer-silicate based renders and paints, lime plasters and fillers

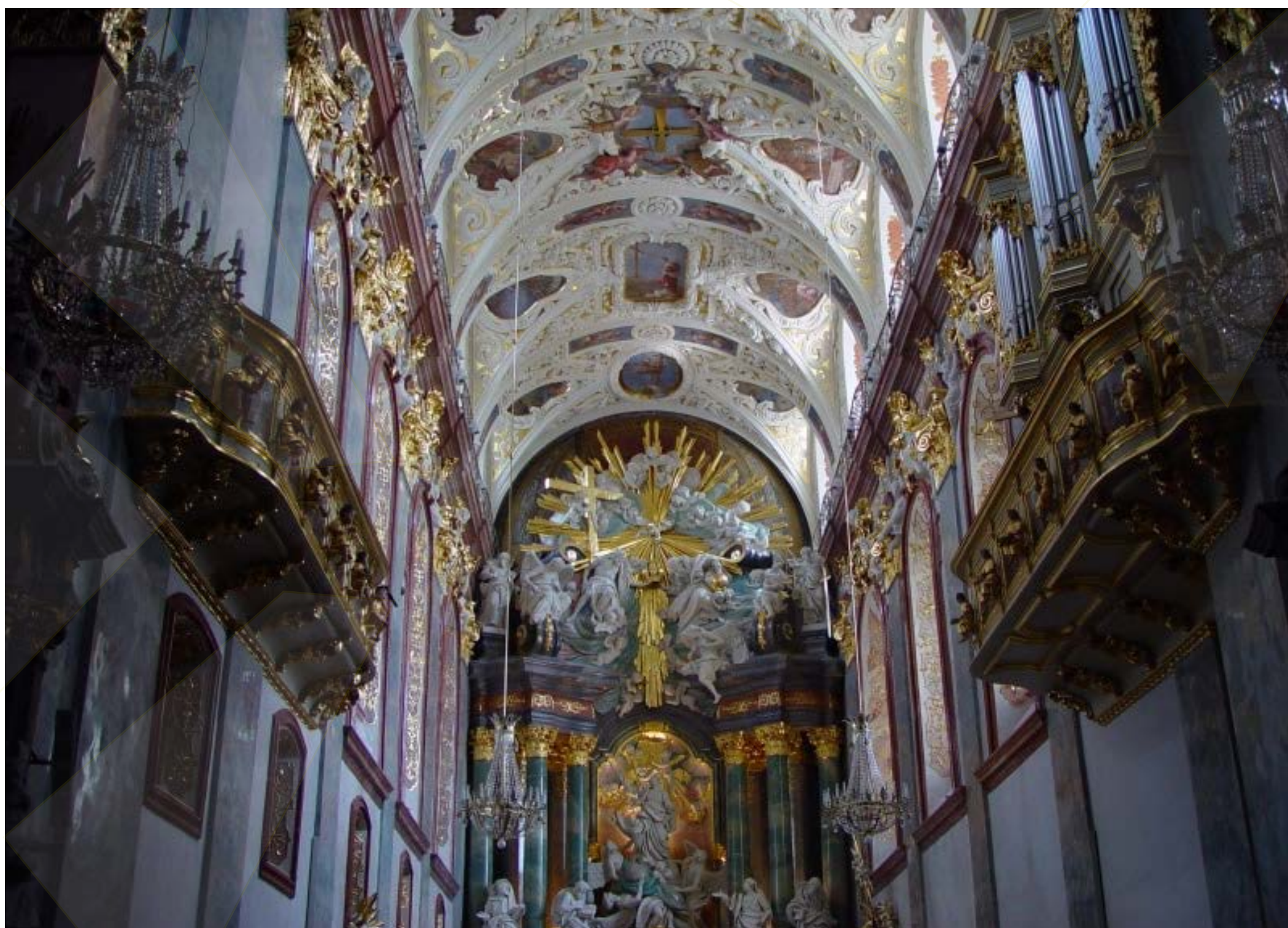


Other - Europe, various locations
products used: various



Jasna Gora Monastery - Czestochowa, Poland

products used: polymer-silicate based plasters and paints, silicate paints



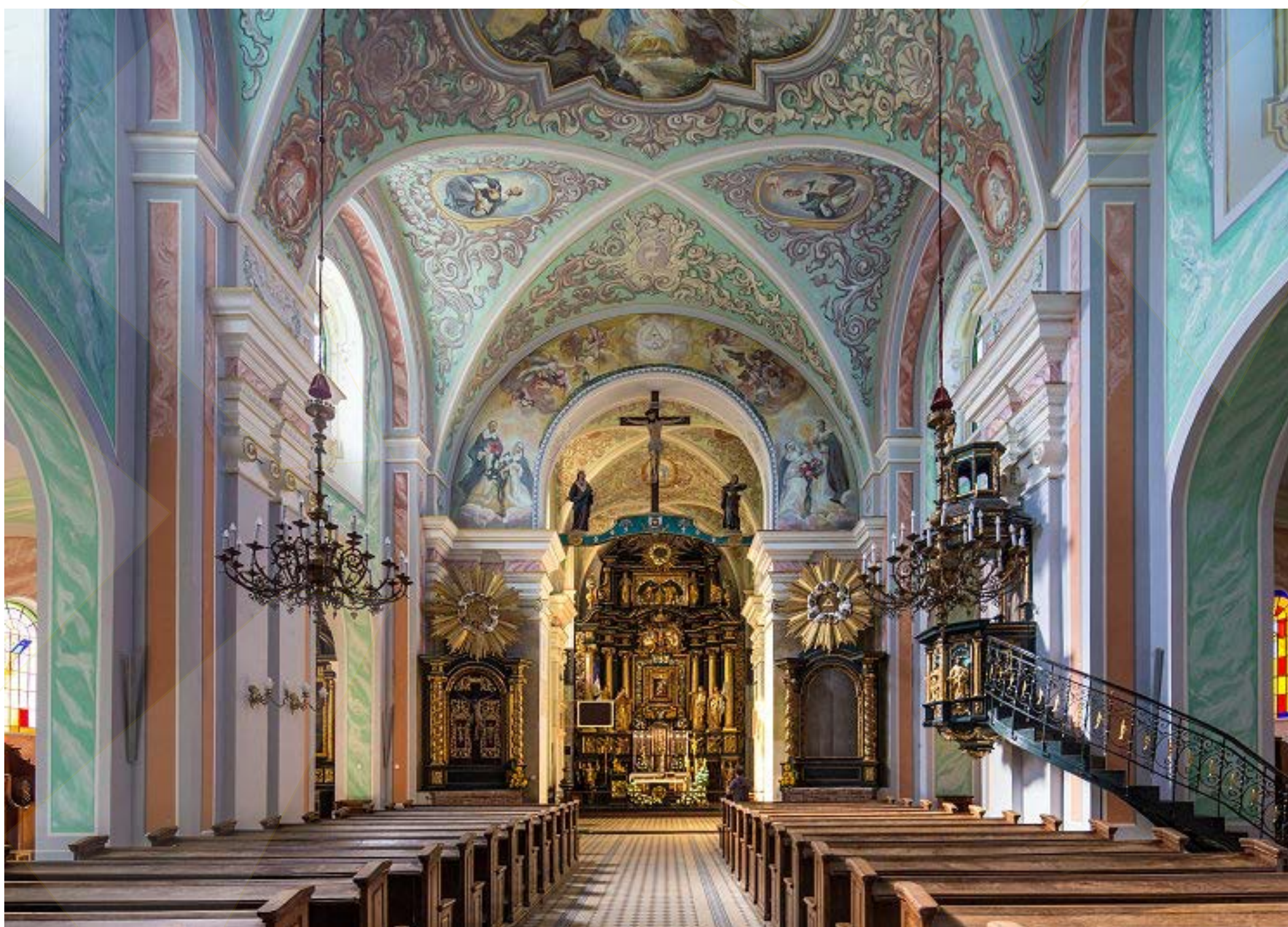
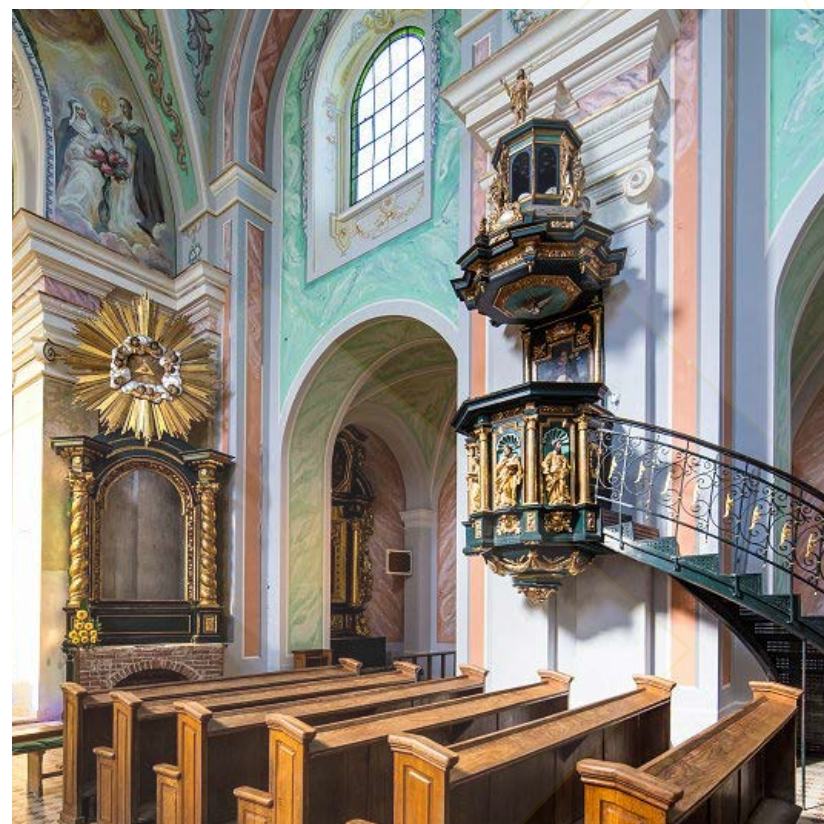
Jasna Gora Monastery - Czestochowa, Poland

products used: polymer-silicate based plasters and paints, silicate paints



Dominika Monastery - Tarnobrzeg, Poland

products used: polymer-silicate based plasters and paints, silicate paints



Other - Europe, various locations
products used: various



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Official distributor:

main properties:

- very high adhesion to porous and absorbent substrates
- traditional lime based formulation
- suitable for internal and external use
- easy mechanical application
- reducing surface absorption
- extended open time
- micro fibre reinforced
- very high plasticity and workability
- highly reduced curing time vs sand and cement renders
- very high vapour permeability
- suitable for winter application*

product description and areas of application:

Dry, mineral levelling base coat based on hydraulic adhesives (lime) and selected aggregates (including light aggregates) for manual or machine application.

It is especially recommended as a part of **TERRIX® POLYMER-SILICATE W1** two coat renders system. It may be applied on all typical mineral substrates such as, e.g. concrete, light weight concrete, expanded clay aggregate, ceramic brick and silicate brick as well as porous ceramics.

For listed buildings or where very high level of vapour permeability is required **Terrix® RD-LB** can be used as an internal levelling base coat before application of **Terrix® PL-SX-S** spray plaster and **Terrix® IP-ST-P** premium polymer-silicate paint.

technical data:

Base binder: hydraulic adhesives (lime);

Grain size: to 0.6 mm;

Colour: naturally white or grey;

Mixing ratio: 5.5+6.0 litres of water per 25 kg of mortar;

Usage: after adding an appropriate amount of water it is possible to obtain around 23 litres of ready-to-use mortar from one packaging of the product;

Application time after adding water: not less than 2 hours;

Processing time: (depending on the type of substrate and ambient humidity and temperature)

- from application to levelling ca. 30 minutes;
- from levelling to spreading 2-5 hours;

Consumption: ca. 1.1 kg/m² per each 1 mm of the layer thickness;

Temperature of application (air and substrate): from +0°C to +15°C;

Curing temperature: from -10°C to +15°C

Compressive strength: cat. CS I;

Water absorption: cat W2;

Adhesion: ≥ 0.2 N/mm²;

Water vapour permeability coefficient μ : ≤9;

Heat conductivity coefficient: λ ≤ 0.37 W/m·K for P=50%, λ ≤ 0.42 W/m·K for P=90%

Reaction to fire: class A1;

Packaging: Disposable paper bags containing 25 kg of product;

Storage: The product should be stored in its original sealed packaging, in a dry frost-protected room. Note: The product must be kept out of the reach of children;

Shelf life: 12 months from manufacture date specified on the packaging, provided that the storage requirements are observed. It is recommended to use the product within 6 months;

application:

Substrate preparation:

Apply to a sound and clean substrate (without cracks and delaminations), degreased, even and dry, and biological or chemical efflorescence free). The substrate should be free of algae/fungi growth.

In case of microbial contamination, the substrate should be cleaned with a power washer. Subsequently **Terrix®PR-AR** solution for removing microbial contamination to be applied as per product manual. Any loose layers that are not bonded to the substrate (such as loose plasters or flaked paint coats) should be removed. Wash and degrease old and/ or dirty substrate with water and product **Terrix® PR-CL** cleaning agent. Before applying the levelling compound/render - refer to the product manuals and data sheets. Smooth substrates require scratch coat to be applied before **TERRIX® RD-LB-W** application.

Note: If product is being used as a part of **TERRIX® W1** render systems refer to the system manual for detailed application instructions.

Preparation:

Use a container with a measured amount of fresh water (6+7l per 25kg of mortar), pour the entire content of the package and mix thoroughly with a mixer /low-speed drill with a basket mixer until homogeneous and lump-free. Leave for approx. 5 minutes to initiate a chemical reaction. Immediately before use mix thoroughly again. Depending on the temperature and humidity ready mix is suitable for use for approx. 2 hours. If required, add a small amount of clean water (max. 0.1l per 20kg of the product). Quantity of added water may vary for different substrate types, weather conditions and application method.

Application method:

Render should be applied onto the substrate by using a steel trowel. After the initial application of mortar smooth with a sponge or felt. In large areas, it is recommended to use rendering pump.

Recommended application thickness of a single layer of render:

indoor ceilings - min. 10mm;

indoor walls - min. 10mm;

external use - min. 15mm (12mm - if part of **TERRIX® W1** System).

For thicker application exceeding 20mm, the product should be applied in two coats with the "wet on wet" method. At wall joints with other building materials and in the presence of furrows a layer of reinforcing mesh should be embedded (145 ÷ 165 g / m²). Use reinforcing mesh stress patches on all openings. Refer to detail drawings.

Warning:

The product is alkaline, use PPE to protect eyes and skin. During work use protective clothing. In the case of contact with eyes, rinse immediately with plenty of water. If irritation occurs, contact a doctor. Refer to safety data sheet.

Drying:

Typical binding time is ca. 1mm of the product per one day (15°C, 55% RH).

Note: Drying time may be longer in low temperatures and high relative humidity. To protect the top coat against inclement weather conditions, scaffolding should be covered with some protective netting or tarpaulin. Avoid applying in direct sunlight or during strong winds.

Useful hints:

The final effect may depend on the substrate type. For non-uniform substrates, block walls with deep grooves it is recommended to skim at first the whole surface. 'Wet on wet' method should be used. All tools should be cleaned with water after work is completed.



TERRIX[®]

BUILDING AND
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Terrix[®] PL-SX-S spray plaster

V.1.1.F 2019/08

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TERRIX[®]
plasters

pcc
Therm UK

Terrix® PL-SX-S is ready-to-use plaster coat for machine levelling of interior walls and ceilings. For final levelling and smoothening of surfaces before painting. Its white colour and smooth surface allow for a reduction in the number of coats necessary to obtain a full decorative effect. When set and hardened, very easy for sanding. Suitable for use on all typical mineral surfaces (such as concrete, cement, limestone, lime and gypsum plasters and plaster boards). Due to its chemical formulation, the product dries even when higher relative humidity levels occur.

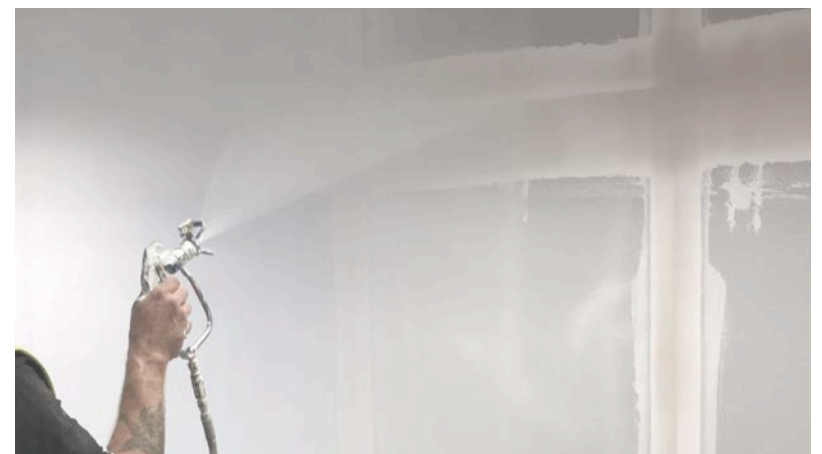
The benefits of Terrix® PL-SX-S spray plaster over traditional skim coats.

Benefits to the customer:

1. Higher productivity outputs - up to 500m²/man/day
2. Due to the full vapour permeability of the Terrix® spray plaster there is no need to wait for taping and jointing to be fully dry - the product can be applied on the same day.
3. Chemical bonding - the product is permanently connected to the substrate. There is no risk of cracking or flaking.
4. Chemical accelerated set - the product is less sensitive to weather conditions meaning Terrix® spray plaster is ready for painting usually next day, in extreme situations after 3 days. Traditional skim coats and competitor's spray coats during winter conditions needs up to two weeks to be ready for painting.
5. Very clean application process - spray plaster is premixed and does not required water or mixing on site. Additionally there is almost no overspray which means very little cleaning after application.
6. The quality of the finish is much better then standard skim coat plastering or other systems . It is delivering a very smooth, decorative surface quality not achievable with skim coat plastering.
7. The Terrix® Spray Plaster is fully compatible with Terrix® premium dispersion-silicate paint.
8. The chemical formulation of the product and its application prosperities allow for more consistent finish leading to very little snagging.
9. Health and safety benefits:
 - Less operatives on site leading to reduced risk of accidents.
 - Reduced risk of falling from heights - ability to spray up to 3m without scaffolding.
 - Very clean application process - spray plaster is premixed and does not required water or mixing on site. Additionally there is almost no overspray which means very little cleaning after application.
 - Reduced dust risk on site. If Terrix® Self-levelling spray plaster is used, no sanding is required.
 - No mist produced during spraying - safe for application without dusk masks.

Benefits to the applicator (subcontractor):

1. Lower labour cost due to the increased output. Up to 500m²/man/day.
2. Ready to use - no mixing or water on site required.
3. Less skilled labour required due to the ease of application. Terrix® spray plaster is extremely easy for spraying, wiping and sanding.
4. Minimising days on site - Due to the products permeability and partly chemical set capabilities the work process can be accelerated, in return releasing the areas ahead of program for others trades.
5. Highly reduced snagging due to consistent finish.
6. Easy sanding - for initial 20 days after application the product is very easy for sanding.
7. Silk consistency - very little snagging after application.
8. Chemical accelerated set - ready for painting usually next day, in extreme situations after 3 days.



TECHNICAL SPECIFICATION

Base binder: organic adhesive;
Colour: white; can be tinted;
Maximum thickness of one layer: up to 3 mm;
Average coverage: ca. 1kg/m² (applied on plasterboard);
Temperature of application (air and substrate): from +5°C to +25°C;
Maximum relative humidity: ≤ 85%;
Adhesion/cohesion (drywall): >0.25 [N/mm2];
Concrete substrate adhesion: ≥0.3 MPa;
Resistance to cracking: no cracks within the zone up to 50 mm from the thin wedge end.
Packaging: Single-use plastic packaging of 30 kg.
Storage: The product should be stored in its sealed packaging in a cool, but frost-protected room.
Shelf life: 12-month shelf life from date of production (production date and batch no. printed on the side of the packaging).

AREAS OF APPLICATIONS

Ready-to-use plaster for machine application of wall and ceiling surfaces inside buildings. Terrix® PL-SX-S is especially recommended as an alternative for skim coats and traditional internal plasters (with Terrix® RN-FC). Thanks to its white colour and smooth surface it allows to reduce a quantity of paint needed to achieve a full decorative effect. The product has a form of easy to apply compound, which after hardening, is very easy for sanding. Terrix® PL-SX-S can be applied on all types of mineral substrates such as concrete, cement renders, cement-lime renders, lime renders as well as skim coats and drywall.

Note: The product should not be used in rooms where constant relative humidity exceeds 70%.

APPLICATION METHOD

SUBSTRATE PREPARATION: Apply to a sound and clean substrate (without cracks and delaminations), degreased, dry, and biological or chemical efflorescence free. The substrate should be free of algae/fungi growth. In case of microbial contamination, the substrate should be cleaned with a power washer. Terrix® PR-AR to be applied as per product manual. Any loose layers not bound to the substrate (i.e. dirt, dust, loose render or flaked coatings) should be removed. Old and/or dirty substrates should be washed off and degreased with water and CLEANFORCE agent. Existing holes, unevennesses and cracks should be filled in pursuant to the best construction practices. Substrates covered with well-set dispersion coating should be ground with a sandpaper and dedusted before the product application. Please note: if the product is applied on newly completed mineral substrates (i.e. cement-lime renders, cement-renders and concrete substrates) – a min. 2-week curing period is required.

PRIMING: Absorbent substrates should be primed with Terrix® PR-UA before spray plaster application.

PRODUCT PREPARATION: Product intended for direct use – do not dilute. Before application, the product should be thoroughly mixed.

APPLICATION: Apply a thin, uniform layer of product on the substrate at a thickness from film to 3 mm, using a spraying machine (airless method). In order to do it, special tools intended for applying spray plasters should be used (e.g. T-MAX of GRACO), as well as suitably powerful devices for the application of paints (e.g. MARK V of GRACO company or SPEEFLO PT6900 XLT DI of WAGNER company). While spraying, the gun should be directed perpendicularly towards the substrate at a distance of ca. 1.0÷1.2 m (T-Max GRACO) and ca. 0.5÷0.6 m (Mark V GRACO)

If greater unevenness is present, the material should be applied in a few layers after the previous layer hardens. After the surface dries, it may be sanded.

DRYING: 3 mm of he product applied on the substrate can be subject to further processing after ca. 12 hours (20°C, 55% RH). Substrate water absorption and air circulation in the room may significantly affect the drying time of the product.

USEFUL HINTS: To be applied on days with temperatures (air and substrate) between 5-25°C. All tools to be cleaned with water after finishing work.

comparison of systems

	property	traditional skim coat	PCC TERRIX® PL-SX-S spray plaster coat	Notes
1	Type of product	powder mixed with water	ready to use	very clean vs skim, does not required water
2	Application	manual	spray	
3	Speed of application	slow	very fast	2X 2 bed apartment per day/ one person
4	Processing	wet	easy sand	no mechanical sanders required
5	Drying	evaporation	chemical accelerated	suitable for winter application
6	Application time	slow	very fast	up to 500m2/day per person
7	Flatness	depends	very high	excellent surface quality
8	Price	low	low	comparable price to skim systems
9	Possibility to tint	none	can be tinted	

Popular spray plaster vs Terrix® PL-SX-S

		Popular spray plaster	Terrix®	Notes
1	No of coats	Two coat application required	One coat application;	Due to the chemical, permanent bonding, one coat application is sufficient without creating any risk of cracks or delamination. Competitor's product creates a film on top of plasterboard, and the bonding is mechanical.
2	Shelf life	9 months of manufacture	Min. 12 months;	The different formulation allows for a longer shelf life. Terrix® spray plaster is usable even after a few years.
3	Coverage	Up to 22m2 per 25.0kg bag at 1mm thickness. 1.5mm min thickness required. Real usage - 16m2 from one bag	30m2 per tube , approx. usage 1kg/m²;	Terrix® usage is 40% lower.
4	Application thickness	Applied as 1-2mm thick, after 2 coat application.	0 (film thickness) - 3mm in one coat;	Due to chemical bonding, there is no minimum thickness required. The product partly sinks into the plasterboard and provides additional reinforcement to it.
5	Application themperature	Should not be used below 5oC or above 30 deg C. Max air humidity 65% R.H.	5+ to 25deg C. Max air humidity 85% Rh;	Terrix® can be applied even during typical British winters when relative humidity is very high.
6	Joint filler	Allow to stiffen, typically 12-24 hours, this is dependent on adequate ventilation.	Ready to apply after 1-1.5h after joint filler application;	Due to the very high vapour permeability of the product, there is no long waiting time for joints to be dry. Once joints are touch dry Terrix® spray application can start.
7	First coat	Apply an even first coat of spray plaster to the walls and ceilings. Level flat with a levelling tool (spatula/ trowel).	The same as the other product;	
8	Corners	After 10 minutes finish internal/ external angles with a corner trowel.	No waiting is required;	10 minutes waiting is not required. The trowel can be used straight away.
7	Drying	Allow to dry, this will typically take12-24 hours.	12-24h even in unfavourable weather conditions due to partly chemical drying;	Terrix® plaster dries much quicker due to its accelerate chemical properties. The other product dries only by evaporation, which means in winter months it may take up to a week for to be suitable for sanding.
8	Second coat	Apply the second coat of spray plaster and repeat the process from the first coat, but this time applying more pressure to flatten the surface. Allow to dry, this typically takes12-24 hours.	Second coat is not required;	Terrix® is one coat system.
9	Repairs	All damaged areas must be repaired prior to the application of the spray plaster. Once complete apply spray plaster in accordance with manual.	Repair to the wall can be made before or after Terrix® spray plaster application;	Repairs can be done at any time as the product can join with existing coatings. Terrix® spray plaster is very easy for spot repairs which are not visible after application.

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**Results of Plaster Analysis to
selected spaces within Manchester Town Hall**



March 2019

MANCHESTER TOWN HALL

Summary

Project	Investigation of plaster finishes to selected spaces within Manchester Town Hall.
Nature of project	Investigations to inform proposed refurbishment of the building.
List Entry Number:	1207469
Listing:	Grade I
Date first listed:	25th February 1952
Name and address of Main Contractor:	Conlon Construction Ltd Charnley Fold Lane Walton-le-Dale Preston PR5 6BE
Name and address of Architect:	Helen Walker Purcell St James's Building 79 Oxford St Manchester M1 6FQ
Name and address of Conservator:	Hirst Conservation Limited Laughton, Sleaford Lincolnshire NG34 0HE
Date of works:	October 2018 – February 2019
Author(s) and date of report:	Paul D'Armada and Elizabeth Hirst Hirst Conservation Ltd
Methods employed:	Plaster sampling from ground level and mobile scaffold tower; Visual appraisal of plaster; Compositional analysis of plaster samples; production of recommendations.

Neither the whole nor any part of this report, or any reference contained within, may be included in any published document, circular or statement, or publish in any other way, without Hirst Conservation Limited's written approval of the form and content in which it may appear.

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1. Introduction

The following document records the investigation of plaster finishes to selected spaces within Manchester Town Hall. The investigation relates to intrusive surveys undertaken as part of the Our Town Hall programme and the research was undertaken between January and March 2019 by plaster specialists and analysts from Hirst Conservation Limited. The results of analysis and observations are included within this report, which also includes an outline methodology for repairs.

2. Rationale and Methodology

Rationale

Mortar analysis can be an essential part of the restoration of historic buildings, because mortars are usually specifically formulated to work in sympathy with the fabric, structure and environment of a building and can therefore be very varied in nature and performance.

Any replacement, replication, or repair mortars generally need to be as similar to the original as possible (as long as these have served the building well), or at least look the same and perform in the same way.

Analysis of a mortar can tell us the source of its constituent materials, their suitability in the first place, as well as the possible causes of any failure.

What is most often required from the analysis of a mortar is its mix ratio by volume (Aggregate: Binder) and the characteristics of its binder and aggregate.

The analytical techniques employed essentially give the main components of the mortar expressed in common terms, i.e.:

- % Dolomite
- % Aggregate
- % Gypsum
- % Iron Compounds
- % Water Soluble Salts
- % Uncarbonated Lime
- % Cementitious compounds.

The mix ratio (by mass and volume) of the mortar and its likely binder type can be determined or extrapolated from the results of the analysis.

A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques are used, in addition to polarised light microscopy, in order to determine the components and characteristics of the mortar sample. These together with the results are presented in table form for the mortar, binder and the aggregate.

Methodology

Collecting Samples

The samples were carefully collected using an oscillating cutter from locations identified on the survey sheets provided by the consultant and put into sealed sample bags. The bags were clearly labelled with the site name and location, the time and date of sampling, as well as the specific location of the samples, their elevation and aspect etc. relative to the building, together with their thickness, number of discernible layers, condition, and the type and condition of their substrates and any other relevant information.

Analysis Techniques

Visual Description:

A visual description of each plaster/mortar sample is given, aided by magnifying glass and microscope if necessary, noting the number of layers present, their colour, texture, grading, thickness, hardness (Moh scale), and any visible inclusions (mineral, hair and other), their specific hardness and character as determined when carefully ‘grinding’ down the mortar for chemical analysis.

Chemical Analysis:

Each layer was analysed separately.

An appropriate amount of the sample was taken (ensuring it contains material representative of the whole), dried and gently ground down using mortar and pestle, teasing out any inclusions for individual analysis if required (e.g. chalk inclusions can be identified from their microfossils, using a polarising microscope and gypsum by micro-chemical and microscopic means).

A weighed amount of the ‘crushed’ sample was then disaggregated in hydrochloric acid and the amount of carbon dioxide emitted measured, from which the carbonate content of the mortar can be determined (carbonated lime/chalk/limestone and dolomite).

A small (1gram) sample of the crushed mortar was kept for determination of any uncarbonated lime ($\text{Ca}(\text{OH})_2$) present.

In addition, some of the crushed sample was dispersed in de-ionised water to semi – quantitatively determine the amounts of water soluble sulphates, chlorides and nitrates present.

The acid extract from disaggregation was then filtered to collect the acid insoluble fraction of the mortar (sand, hair straw etc.). These acid insolubles were heated with sodium carbonate to ensure extraction of all the soluble silica (combined silica from any cementitious compounds) and the solution filtered, the filtrate being added to the original acid extract for further tests. The remaining acid insolubles were washed, dried and weighed to determine their percentage in the mortar (this is essentially the % aggregate).

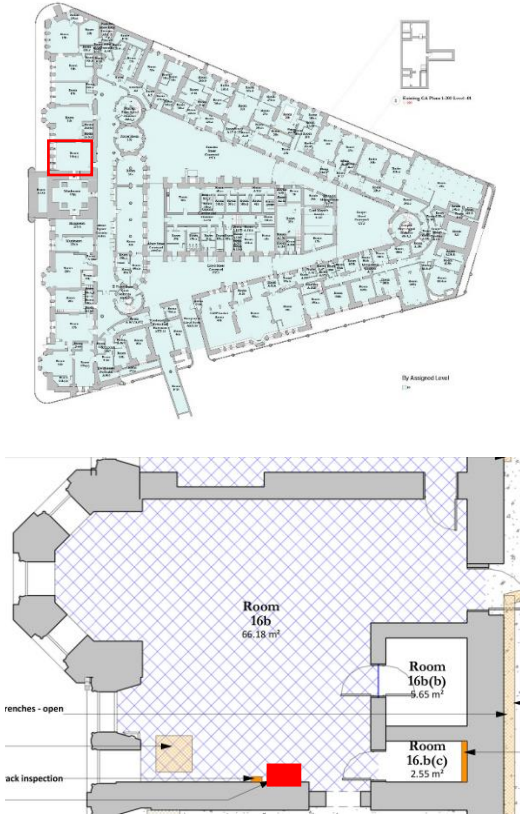
The combined extract was separated into measured volumes for determination of soluble silica (by a titrimetric method measuring silica precipitated within an 8 hydroxyquinoline complex), calcium sulphate (by standard gravimetric barium chloride method), calcium oxide/magnesium oxide (using ammonium oxalate) and Fe_2O_3 content (by test strips or titration with potassium dichromate after reduction to ferrous salts).

From these results the **mix ratio** of the mortar (Aggregate: Binder) by mass and by volume was determined. In addition, the **Cementation Index (CI)** and **hydraulicity** of the binder was estimated, which indicates the type of binder used, whether this might be a fat lime (lime putty), a feebly, moderately or eminently hydraulic lime (NHL1-2, NHL3.5 or NHL5), or a cement.

Aggregate Mode:

The aggregate was passed through a series of Endecotts sieves to determine its mode, grading and characteristics, which are given in table and graphical form, alongside BS standard and English Heritage preferred gradings for comparison.

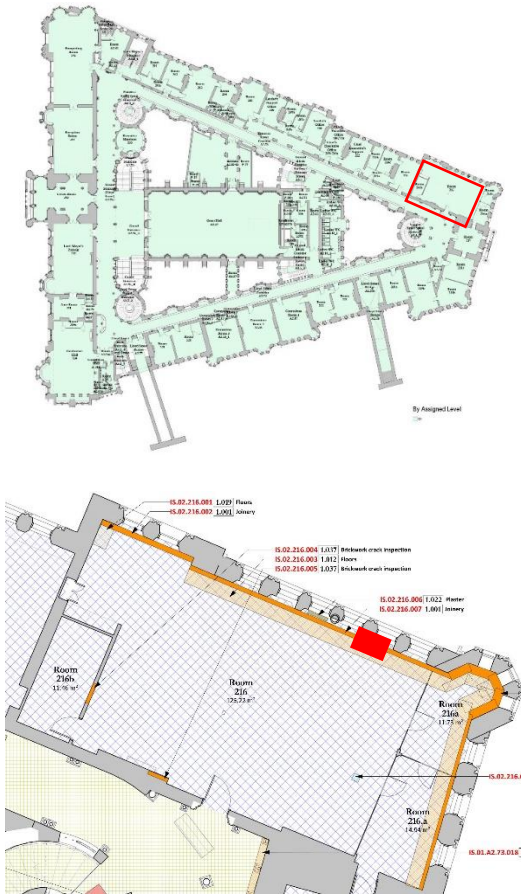
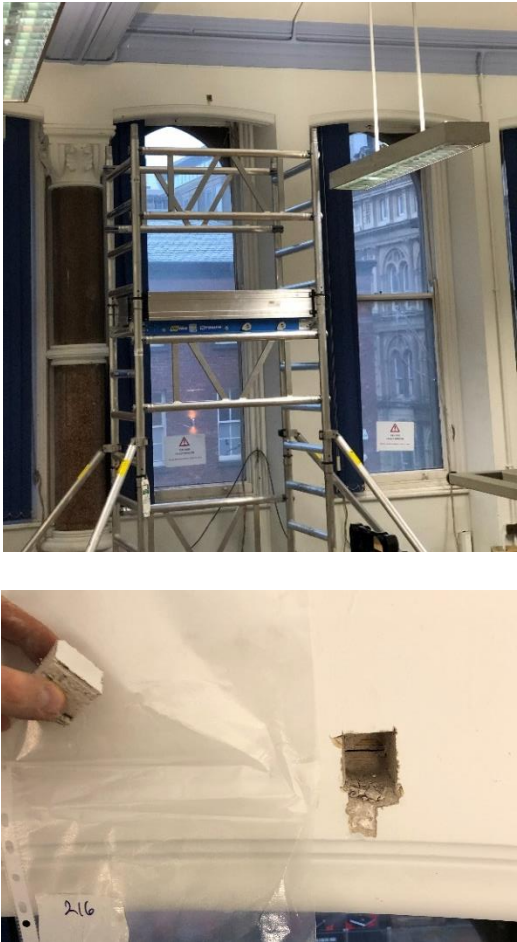
3. IS.B1.16B.002 – Room 16B, wall

Location – Level 0	Photographs
	
Observations and summary of results	
Two coat mortar on brick substrate. Base coat - A 16mm thick, firm but crushable, fine-medium grained, grey coloured mortar, with sparse hair and inclusions of coal/charcoal. The Aggregate: is a fine - coarse grained, dark grey coloured essentially blast furnace iron slag material, which would have had a pozzolanic effect on the binder by virtue of its reaction with lime to produce calcium silicate cementitious compounds, giving added strength and set to the mortar. The binder is equivalent in strength to a moderately - eminently hydraulic, dolomitic lime. It was probably an on-site hot lime mix, which usually gives a low aggregate : binder mix ratio by volume, although in this case the mix ratio is acceptable. Gypsum does not appear to be a significant proportion of the mix, but may have been added to increase the set. Mix ratio by volume of 1.7 – 2 : 1 aggregate : binder. Top coat - A 2mm thick, off-white coloured, fine grained, hard mortar. The Aggregate: is a mostly a light warm buff coloured, fine grained sharp silica sand, with some grey/black pozzolanic coke and iron oxides + off-white/grey lithic fragments. The binder is 1 part Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) 1.8 parts Feeble - Moderately hydraulic, dolomitic lime. Mix ratio consists of 2.9 parts Aggregate : 1 part Gypsum : 1.8 parts Dolomitic lime.	

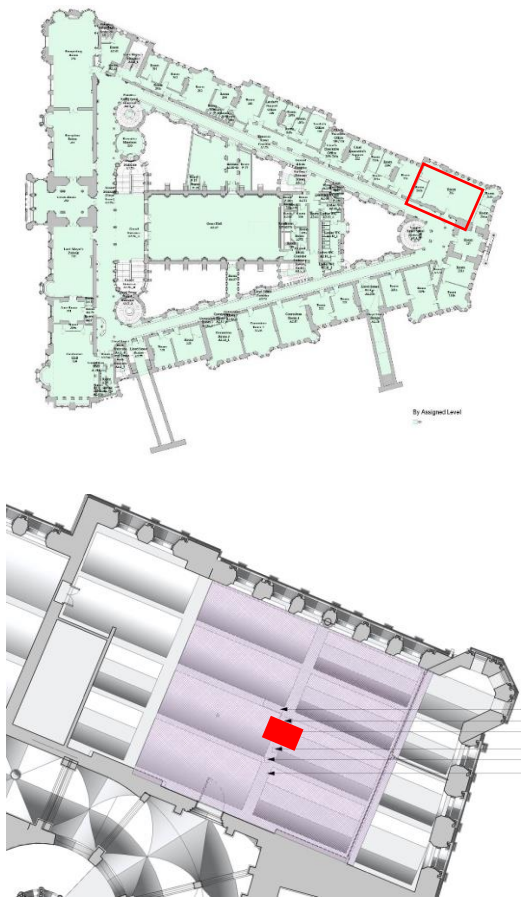
4. IS.01.102.003 – Room 102, wall

Location – Level 1	Photographs
The top image is a Level 1 floor plan of Manchester Town Hall with Room 102 highlighted in red. The bottom image is a detailed architectural cross-section of Room 102, showing its dimensions (121.22 m²) and adjacent rooms (Room 102.a: 5.71 m², Room 102.b: 2.59 m²). The section also shows structural elements like the service riser and various inspection points.	The top photograph shows the interior wall of Room 102, featuring wood paneling and a 'FIRE EXIT' sign. The bottom photograph shows a close-up of a hand holding a sample of the plaster material, which appears to be a mix of mortar and aggregate.
Observations and summary of results	
Two coat plaster on lath. Base coat - A 23 – 30mm thick, grey coloured, fine-medium grained, firm but readily crushed mortar with sparse hair and some coal/charcoal inclusions. The Aggregate: is a light grey-brown coloured, fine-medium grained mostly sharp silica sand (warm buff coloured) + a pozzolanic blast furnace iron slag material. The Binder: is 1 part Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) + 2.7 parts Moderately hydraulic, dolomitic lime. The Mortar: consists of 66 parts Aggregate : 1 part Gypsum : 2.7 parts Dolomitic lime. Top coat - A 2 - 3mm thick, off-white coloured, quite hard, fine grained mortar. The Aggregate: is mostly a light warm buff coloured, fine grained sharp silica sand, with some grey/black coke and iron oxides (pozzolanic slag) + off-white/grey lithic fragments. The Binder: is equivalent in strength to a moderately hydraulic, dolomitic lime. It was probably an on-site hot lime mix, which usually gives a characteristically low aggregate : binder mix ratio by volume. The small amount of slag material may have given the mortar a degree of hardness and set, by virtue of its reaction with the free lime content, producing cementitious calcium silicate compounds. The Mortar: has a mix ratio by volume of 1.1 – 1.3 : 1 aggregate : binder.	

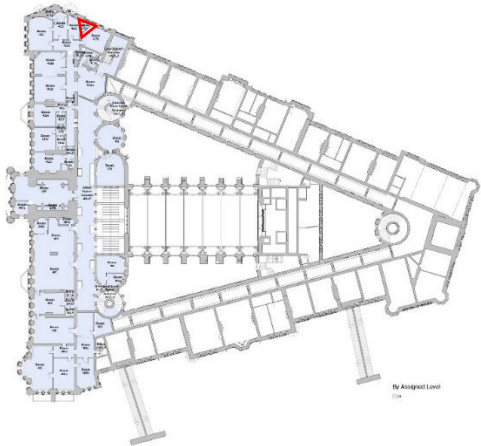
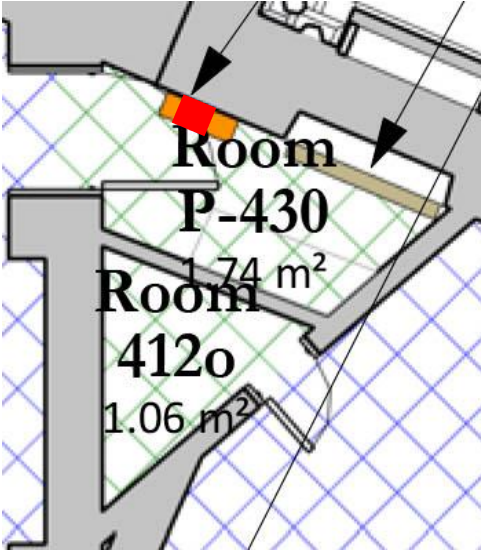
5. IS.02.216.006 – Room 216, wall

Location – Level 2	Photographs
	
Observations and summary of results	
Two coat plaster on lath. Base coat – A 28mm thick, light - mid grey coloured, quite hard mortar, fine – medium grained with inclusions of coal/charcoal and sparse hair. The Aggregate: is a light grey-brown coloured, fine-medium grained mostly sharp silica sand (warm buff coloured) + a pozzolanic blast furnace iron slag material. The Binder: is 3.2 parts Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) + 1 part Moderately hydraulic, dolomitic lime. The Mortar: consists of 4.2 parts Aggregate : 3.2 parts Gypsum : 1 part Dolomitic lime. Top coat - A hard, light grey coloured, fine grained, 2mm thick mortar. The Aggregate: is mostly a light warm buff coloured, fine grained sharp silica sand, with some grey/black coke and iron oxides (pozzolanic slag) + off-white/grey lithic fragments. The Binder: is 1.9 parts Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) 1 part Moderately hydraulic, dolomitic lime. The Mortar: consists of 1.7 parts Aggregate : 1.9 parts Gypsum : 1 part Dolomitic lime.	

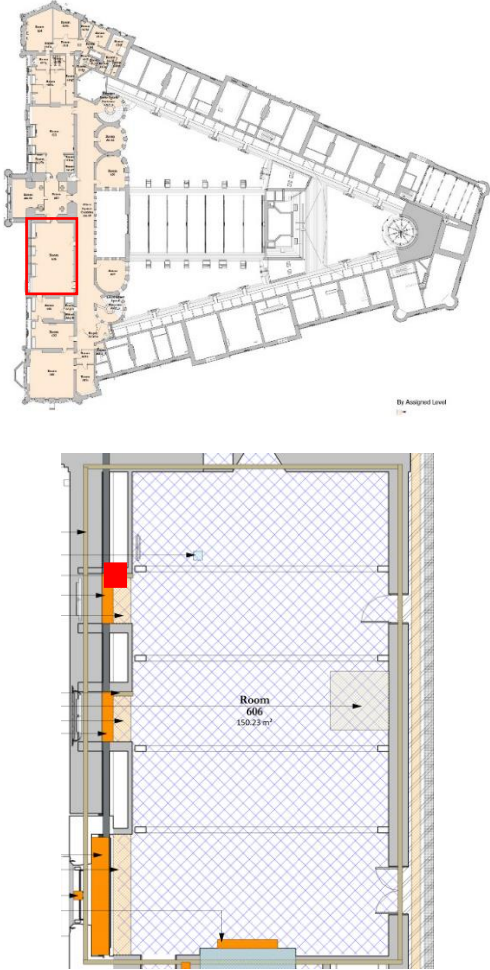
6. IS.02.216.012 – Room 216, ceiling beam

Location – Level 2	Photographs
	
Observations and summary of results	
Two coat plaster on lath. Base coat – A 13mm thick, mid-grey coloured, fine-medium grained, firm but easily crushable mortar with sparse hair and occasional inclusions of black coal/charcoal. The Aggregate: is a light grey-brown coloured, fine-medium grained mostly sharp silica sand (warm buff coloured) + a pozzolanic blast furnace iron slag material. The Binder: is 4 parts Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) + 1 part Moderately hydraulic, dolomitic lime. The Mortar: consists of 11.8 parts Aggregate : 4 parts Gypsum : 1 part Dolomitic lime. Top coat - An 8mm thick, off-white coloured, fine grained, quite hard mortar. The Aggregate: There is negligible aggregate content in the sample analysed. The Binder: is 2.4 parts Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) 1 part Moderately hydraulic, dolomitic lime. The Mortar: consists of 0.05 parts Aggregate : 2.4 parts Gypsum : 1 part Dolomitic lime.	

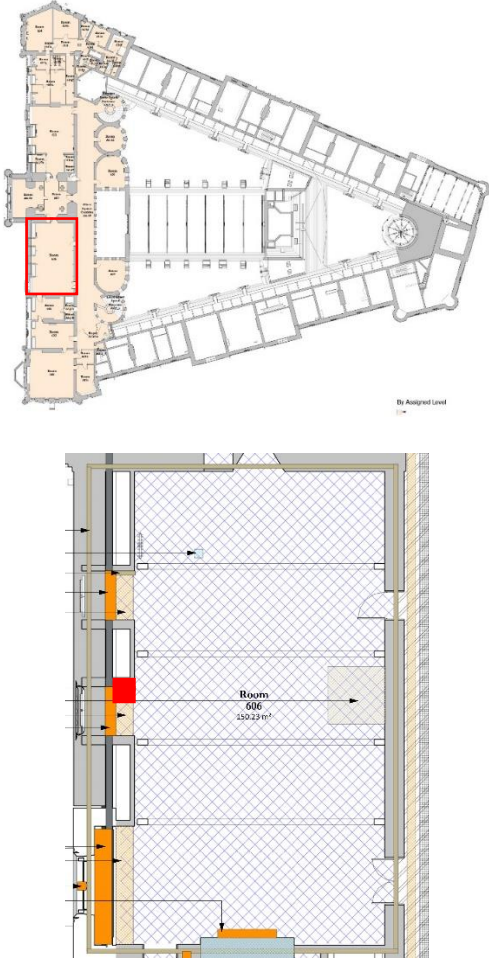
7. IS.04.P-430.001 – Room P-430, wall

Location – Level 2	Photographs
 	  
Observations and summary of results	
Two coat plaster on brick substrate. Base coat – A 20mm thick, fine-coarse grained, dark-grey coloured, quite firm but crushable, hair mortar, with inclusions of black-grey coke and iron oxides. The Aggregate: is a fine - coarse grained, dark grey coloured essentially blast furnace iron slag material, which would have had a pozzolanic effect on the binder by virtue of its reaction with lime to produce calcium silicate cementitious compounds, giving added strength and set to the mortar. The Binder: is 1 part Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) + 7.3 parts Moderately hydraulic, dolomitic lime. The Mortar: consists of 81.8 parts Aggregate : 1 part Gypsum : 7.3 parts Dolomitic lime. Top coat - A 2mm thick, grey coloured, fine grained, quite firm but easily crushed mortar, with sparse hair and coal/charcoal inclusions. The Aggregate: is mostly a light warm buff coloured, fine grained sharp silica sand, with some grey/black coke and iron oxides (pozzolanic slag) + off-white/grey lithic fragments. The Binder: is 5.6 parts Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) 1 part Moderately hydraulic, dolomitic lime. The Mortar: consists of 2.4 parts Aggregate : 5.6 parts Gypsum : 1 part Dolomitic lime.	

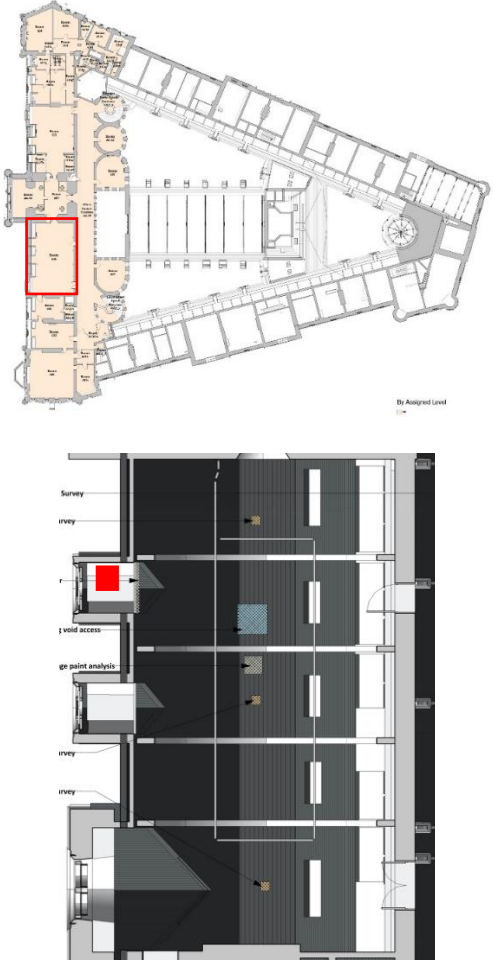
8. IS.06.606.004 – Room 606, wall

Location – Level 2	Photographs
	
Observations and summary of results	
Two coat plaster on lath. Base coat – An 18mm thick, mid-grey coloured, fine-coarse grained, quite firm but easily crushed mortar, with sparse and some inclusions of coal/charcoal. The Aggregate: is a light grey-brown coloured, fine-coarse grained mostly sharp silica sand (warm buff coloured) + a pozzolanic blast furnace iron slag material. The Binder: is 1 part Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) + 2.3 parts Moderately hydraulic, dolomitic lime. The Mortar: consists of 6 parts Aggregate : 1 part Gypsum : 2.3 parts Dolomitic lime. Top coat - A 2mm thick, hard, light grey coloured, fine grained mortar. The Aggregate: is mostly a light warm buff coloured, fine grained sharp silica sand, with some grey/black coke and iron oxides (pozzolanic slag) + off-white/grey lithic fragments. The Binder: is equivalent in strength to a moderately hydraulic, dolomitic lime. It was probably an on-site hot lime mix, which usually gives a characteristically low aggregate : binder mix ratio by volume. The small amount of slag material may have given the mortar a degree of hardness and set, by virtue of its reaction with the free lime content, producing cementitious calcium silicate compounds. The Mortar: has a mix ratio by volume of 0.7 – 0.8 : 1 aggregate : binder.	

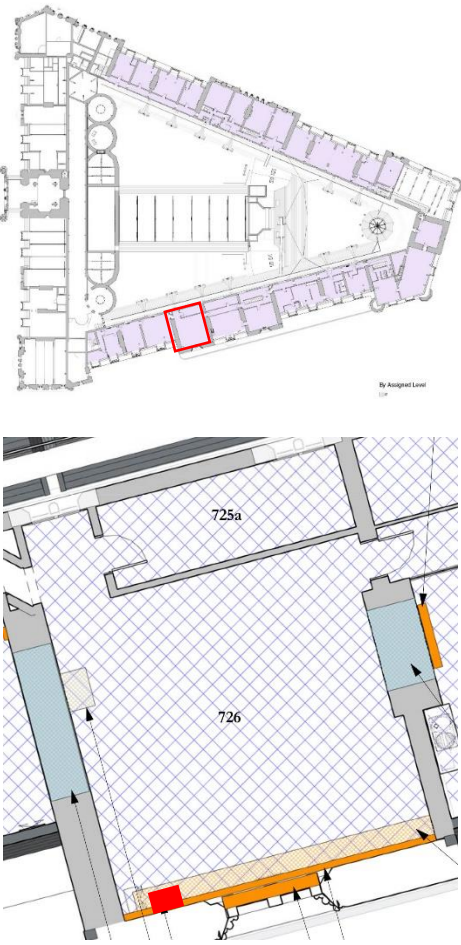
9. IS.06.606.007 – Room 606, wall

Location – Level 2	Photographs
	
Observations and summary of results	
Two coat plaster on lath. Base coat – A 20mm thick, grey coloured, firm but crushable, fine - medium grained mortar with significant hair (compared with other base coats) and inclusions of coal/charcoal, off-white carbonated lime and wood fragments. The Aggregate: is a fine - coarse grained, grey-brown coloured essentially blast furnace iron slag material, which would have had a pozzolanic effect on the binder by virtue of its reaction with lime, to produce calcium silicate cementitious compounds, giving added strength and set to the mortar. The Binder: is 1 part Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) + 2.4 parts Moderately hydraulic, dolomitic lime. The Mortar: consists of 7.6 parts Aggregate : 1 part Gypsum : 2.4 parts Dolomitic lime. Top coat - A 1.5 - 2mm thick, off-white coloured, hard, fine grained mortar. The Aggregate: is a mostly a light warm buff coloured, fine grained sharp silica sand, with some grey/black pozzolanic coke and iron oxides + off-white/grey lithic fragments. The Binder: is equivalent in strength to a feebly hydraulic, dolomitic lime. It was probably an on-site hot lime mix, which usually gives a low aggregate : binder mix ratio by volume. The Mortar: has a mix ratio by volume of 0.7 – 0.9 : 1 aggregate : binder.	

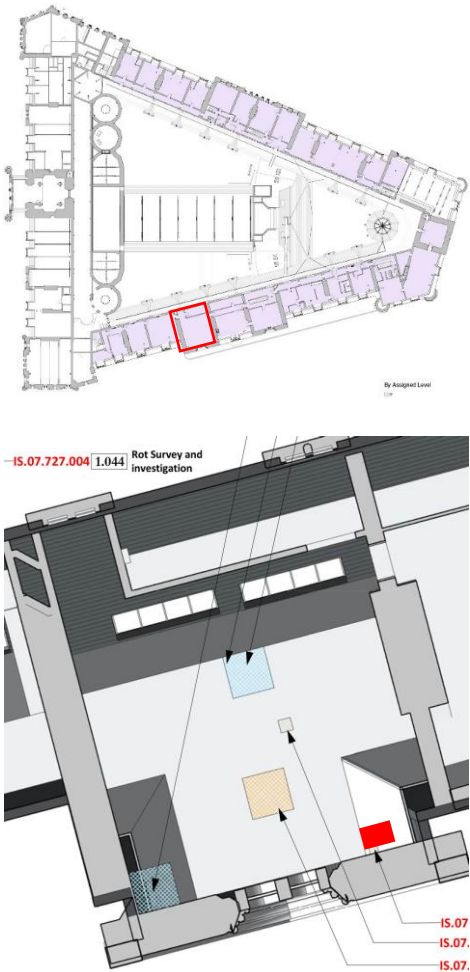
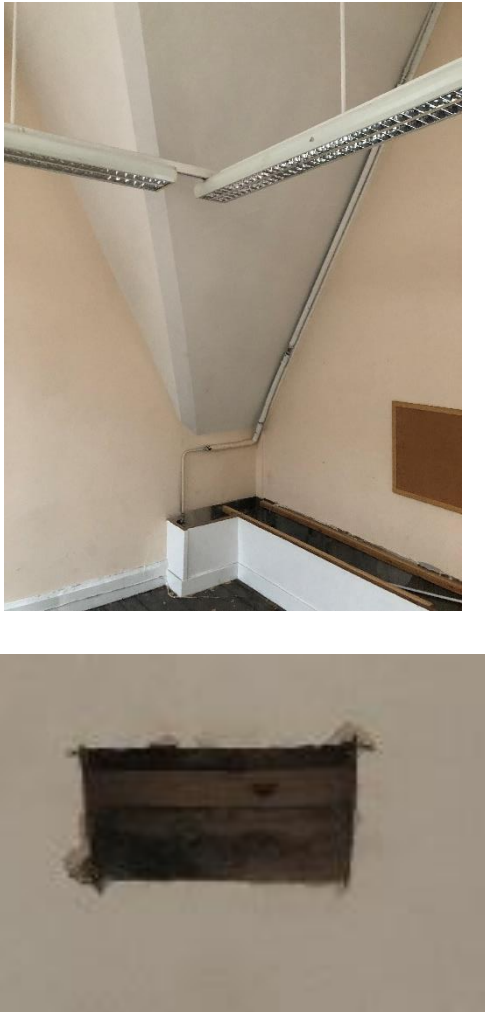
10. IS.06.606.018 – Room 606, ceiling

Location – Level 2	Photographs
	
Observations and summary of results	
Two coat plaster on lath. Base coat – A 30 – 40mm thick, light grey coloured, fine - coarse grained, firm but crushable mortar with hair and inclusions of coal/charcoal, off-white carbonated lime and wood fragments. The Aggregate: is a light grey-brown coloured, fine-coarse grained mostly sharp silica sand (warm buff coloured) + a pozzolanic blast furnace iron slag material. The Binder: is 1 part Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) + 2 parts Moderately hydraulic, dolomitic lime. The Mortar: consists of 4.8 parts Aggregate : 1 part Gypsum : 4.1 parts Dolomitic lime. Top coat - A 1 - 2mm thick, hard, off-white coloured, fine grained mortar. The Aggregate: There is a very small proportion of aggregate in the sample tested, which is otherwise a fine grained buff, sharp buff colored silica sand. The Binder: is 1 part Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) 1.6 parts Moderately hydraulic, dolomitic lime. The Mortar: consists of 0.14 parts Aggregate : 1 part Gypsum : 1.6 parts Dolomitic lime.	

11. IS.07.726.004 – Room 726, wall

Location – Level 2	Photographs
	
Observations and summary of results	
Two coat plaster on masonry/brick substrate. Base coat - A 13 - 15mm thick, reddish-brown-grey coloured, quite hard but readily crushed, fine - coarse grained mortar, with off-white inclusions of carbonated lime and very sparse hair. The Aggregate: is a fine - coarse grained, grey-brown coloured essentially blast furnace iron slag material, which would have had a pozzolanic effect on the binder by virtue of its reaction with lime to produce calcium silicate cementitious compounds, giving added strength and set to the mortar. The Binder: is 1 part Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) + 4.1 parts Moderately hydraulic, dolomitic lime. The Mortar: consists of 53.3 parts Aggregate : 1 part Gypsum : 4.1 parts Dolomitic lime. Top coat - A 1 - 1.5mm thick, off-white coloured, fine grained, quite hard mortar. The Aggregate: is mostly a light warm buff coloured, fine grained sharp silica sand, with some grey/black coke and iron oxides (pozzolanic slag) + off-white/grey lithic fragments. The Binder: is equivalent in strength to a moderately hydraulic, dolomitic lime. It was probably an on-site hot lime mix, which usually gives a characteristically low aggregate : binder mix ratio by volume. The small amount of slag material may have given the mortar a degree of hardness and set, by virtue of its reaction with the free lime content, producing cementitious calcium silicate compounds. The Mortar: has a mix ratio by volume of 0.96 – 1.2 : 1 aggregate : binder.	

12. IS.07.726.011 – Room 726

Location – Level 2	Photographs
 Architectural drawings of Level 2. The top drawing is a plan view showing the layout of the floor, with a red rectangle highlighting the location of Room 726. The bottom drawing is a section view showing the profile of the room, with a red rectangle highlighting the location of the plaster analysis sample. Labels include 'IS.07.727.004 1.044 Rot Survey and Investigation' and 'IS.07'.	 Two photographs of Room 726. The top photograph shows the interior of the room, including the ceiling, walls, and a window. The bottom photograph shows a close-up of a rectangular opening in the wall, which is the location of the plaster analysis sample.
Observations and summary of results	
Two coat plaster on lath. Base coat – A 20mm thick, firm, but readily crushed, fine – medium grained, grey coloured mortar, with sparse hair and inclusions of coal/charcoal. The Aggregate: is mostly a light warm buff coloured, fine grained sharp silica sand, with some grey/black coke and iron oxides (pozzolanic slag) + off-white/grey lithic fragments. The Binder: is 1 part Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) + 2.6 parts Moderately hydraulic, dolomitic lime. The Mortar: consists of 27.4 parts Aggregate : 4 parts Gypsum : 1 part Dolomitic lime. Top coat - A 6 - 7mm thick, hard, off-white coloured, fine grained mortar. The Aggregate: is a mostly a light warm buff coloured, fine grained sharp silica sand, with some grey-black pozzolanic coke and iron oxides + off-white/grey lithic fragments. The Binder: is 1.4 parts Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) 1 part Moderately hydraulic, dolomitic lime. The Mortar: consists of 1.7 parts Aggregate : 1.4 parts Gypsum : 1 part Dolomitic lime.	

13. Overview of mortar analysis results

Samples arranged in groups of mortars with visibly similar aggregates:

Sample	Binder	Mix Ratio Agg.:Binder or Agg.:lime:gypsu m	% Dolomit e in mortar	Aggregate characteristics
Base Coat Plasters				
IS.06.606.018 (ceiling plaster)	Gypsum + lime	4.8 : 2 : 1	-	Mid-grey-brown, fine-coarse grained, sharp silica sand + iron slag material
IS.06.606.007 (wall plaster)	Gypsum + lime	7.6 : 2.4 : 1	0.72	As above
IS.06.606.004 (wall plaster)	Gypsum + lime	6 : 2.3 : 1	2.8	As above
IS.04.P-430.001 (wall plaster)	Gypsum + lime	81.8 : 7.3 : 1	4.6	fine-medium grained, dark grey, essentially blast furnace iron slag material
IS.B1.16B.002 (wall plaster)	Lime	1.7 : 1	3.6	As above
IS.02.216.012 (ceiling plaster)	Gypsum + lime	11.8 : 1 : 4	3.4	Light warm brown, fine-medium grained, sharp silica sand + some iron slag material
IS.01.102.003 (wall plaster)	Gypsum + lime	66 : 2.7 : 1	4.4	As above
IS.07.726.011 (wall plaster)	Gypsum + lime	27.4 : 2.6 : 1	4.5	As above
IS.07.726.004 (wall plaster)	Gypsum + lime	53.3 : 4.1 : 1	1.7	As above
IS.02.216.006 (wall plaster)	Gypsum + lime	4.2 : 1 : 3.2	5.7	As above
Top Coat Plasters				
IS.06.606.007 (wall plasters)	Lime	0.7 : 1	6	Light warm brown, fine-grained, sharp silica sand + some iron slag material
IS.01.102.003 (wall plasters)	Lime	1 : 1	5.5	As above
IS. 02.216.006 (wall plaster)	Gypsum + lime	1.7 : 1 : 1.9		As above
IS.04.P-430.001 (wall plaster)	Gypsum + lime	2.4 : 1 : 5.6	3.7	As above
IS.06.606.004 (wall plasters)	Lime	0.7 : 1	5.3	As above
IS.07.726.004 (wall plaster)	Lime	1 : 1	3	As above
IS.07.726.011 (wall plaster)	Gypsum + lime	1.7 : 1 : 1.4	-	As above
IS.B1.16B.002 (wall plaster)	Gypsum + lime	2.9 : 1.8 : 1	4.4	As above
IS.06.606.018 (ceiling plaster)	Gypsum + lime	0.14 : 1.6 : 1	13.3	Negligible Aggregate
IS.02.216.012 (ceiling plaster)	Gypsum + lime	0.05 : 1 : 2.4	3.9	Negligible Aggregate

Comments:

Analysis of inclusions of carbonated lime in the mortars indicates this is generally dolomitic (Magnesian) lime.

The mix ratios may be greater (more aggregate) and the hydraulic lime binders slightly stronger (>NHL3.5 equivalent) if there is some limestone (probably dolomitic/Magnesian limestone) in the original aggregates, but this could not easily be determined and was considered negligible.

Magnesian limes can have 15 – 20% Magnesium oxide in their composition, such that the % dolomites shown in the tables are consistent with Magnesian lime binders. Magnesian limes are feebly-moderately hydraulic (NHL2 – 3.5) in their own right, containing up to 5 – >10% soluble silica.

The generally low mix ratios by volume given for the dolomitic mortars, suggest that the mortars may have been 'hot-lime' mixes (with gypsum added to some for extra strength and faster set), probably using locally sourced materials from the Permian Magnesian limestones and river sands. The low ratios also suggest that there may be some dolomitic limestone in the original aggregates. The amount, if any, of limestone in the aggregate cannot be known.

The aggregates in all the top coat mortars are essentially the same (fine-grained angular clear/milky/yellow/ rose coloured quartz grains), some with iron slag material and grey/off-white lithic (stone) fragments, some including red brick dust. The base coat aggregates have increased amounts of black-grey iron slag material, lithic fragments and red brick dust, making them generally coarser than the top coats.

In all the base coats there are sparse amounts of hair and occasionally some wood fragments/splinters.

The varying amounts of black material (coal, charcoal, iron oxides) seen mostly in the base coat aggregates, are consistent with a pozzolanic blast furnace iron slag. This may partly be a 'contaminant' from the calcining process but more likely added to give a degree of hydraulic strength (set) to the mortars. It gives most of the mortars a greyish colour. The degree of greyness is dependent on the amount and fineness of the black slag material in each mortar.

The iron slag material imparts added strength and set to the mortars by virtue of its reaction with free lime in the binders, producing cementitious compounds. This effect will vary according the amount and fineness of the slag and the amount of free lime available in the binder. Where gypsum was added in more significant proportions, the binders rely less on this pozzolanic reaction for strength.

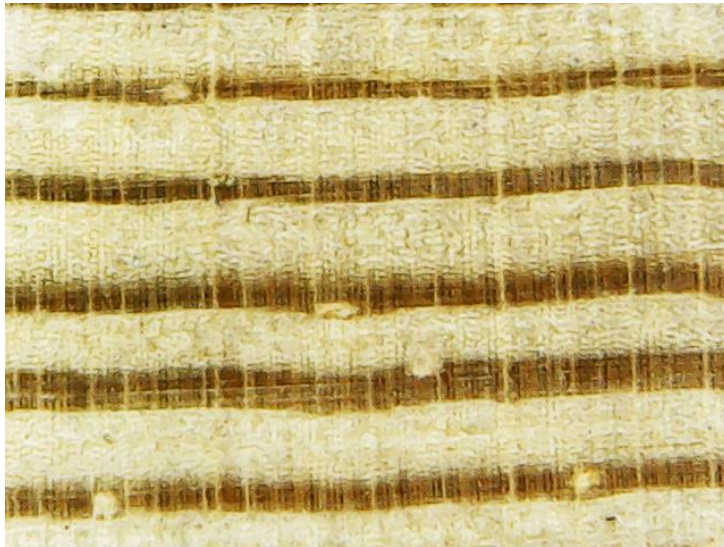
The Magnesian lime binders in the mortars can cause some disruption to their integrity, because they are slow to calcine, hydrate and carbonate (set), so they can hydrate with associated expansion ($\text{MgO} \rightarrow \text{Mg(OH)}_2 \rightarrow \text{MgCO}_3$) in the mortars after they have been applied. In addition, if impacted by acid rain (mostly sulphurous acid), the calcium and magnesium carbonates are converted to calcium sulphate (gypsum) and magnesium sulphate, the latter being up to 130 times more soluble in water than gypsum, thus causing more disruption to porous materials during cycles of dissolution, migration and precipitation of their expansive hydrates.

However, the mortars analysed are all internal plasters, such that they should not have been affected by deleterious environmental conditions. Indeed, the mortar samples analysed all appear to be in a good condition with no signs of delamination or disruption by salts.

14. Summary and repair specification

14.1 Summary of condition

Generally the plaster is in sound and stable condition except where impacted by other factors such as mechanical damage, effect of moisture and salts, etc. It is executed either onto masonry or riven lath. Inspection of the lath under the microscope indicates it is pitch pine (*Pinus rigida*), relatively slow grown, probably northern European, see image below.



USB microscope image of end grain.

In the areas inspected the lath appeared sound and in room 606 the reverse of the lath could be seen through a hatch into a void behind. This illustrates the sound condition and the excellent plaster key formed by the plaster squeeze through the laths.



Image of reverse of laths showing plaster nibs, room 606.

There are areas in the lower walls where fracturing can be seen in the paintwork which appears to go down into the plaster layer, particularly noticeable in room 601 and 606. This should be further investigated as it is impacting on coatings. It may be these areas would have remained wetter for longer as the lower wall would dry more slowly than the upper wall. In addition the presence of magnesium lime would have been slower to calcine, hydrate and carbonate.

If originally the lower plaster sections stayed wet for longer, then the original hydraulic Magnesian lime + gypsum may have produced expansive thaumasite/ettringite hydrate compounds. This could be the reason for historic cracking of the plaster at dado level. The crack investigation should include for a test for the presence of thaumasite and ettringite in the original mortars to see if that was cause of the cracking seen to the lower walls.

14.2 Repair specification

Average mix ratio for original mortar mixes (by volume):

Base coats: 6 : 1.8 : 1 (aggregate : lime : gypsum)
Top coats: 1.6 : 1 : 2 (aggregate : lime : gypsum)

Ceiling Base coats: 6 : 1 : 1.7 (aggregate : lime : gypsum)
Ceiling Top coats: 0.1 : 1 : 1.3 (aggregate : lime : gypsum)

Recommended repair mixes (by volume):

Mortars:

Base coats: 6 : 2 : 1 (aggregate : lime putty : gypsum)
Top coats: 1.5 : 1 : 2 (aggregate : lime putty : gypsum)

Ceiling Base coats: 6 : 1 : 1.5 (aggregate : lime putty : gypsum)
Ceiling Top coats: 0.1 : 1 : 1.5 (aggregate : lime putty : gypsum)

Aggregates:

Base Coat mortars because of their substantial thickness may need to be applied in 2 coats: a dubbing coat and a scratch coat. The aggregate to be a fine – coarse grained sharp sand, and ideally grey-buff in colour if a closer match is required.

Ceiling top coats aggregate to be sieved to 0.5mm down (very fine grained).

Note: just before the base coat mortars are ready for application horse hair should/could be added to the mix approx. 0.5 kg per 100 litres.

Tests should be made to agree the final mortar mixes:

If a colour match is required add a grey-black material such as coal ‘dust’ to the mortar containing the grey-buff sand. However, to be able to visually differentiate between original plaster and replacement is probably preferred.

Reduce the amount of gypsum gauging plaster in each mortar mix (apart from top coats and ceiling plasters), so the binders are more like lime putty mortars gauged with a small amount of gypsum.

Although the plasters are very hard, the mortar mixes have excluded the use of hydraulic lime as this can cause problems: ettringite and thaumasite which are expansive large hydrate crystals and can cause disruption to porous materials if they form, usually as result of prolonged damp. The walls here are probably dry but if they become wet these deleterious forms of calcium sulphate silicate hydrates can be produced. For this reason replication mixes of fat lime and gypsum have been suggested, rather than hydraulic lime.

Gypsum repairs alone on damp walls can cause calcium sulphate to migrate to the older original hydraulic, dolomitic lime mortars (which also still contain active pozzolanic slag material and calcium carbonate, which, particularly together, can react with gypsum in damp conditions, to form thaumasite/ettringite).

Appendix 1: Analysis sheets IS.B1.16B.002 – Room 16B, wall**Date Analysed:** 25/02/19**Sample:** Base Coat Wall Plaster on Brick, IS.B1.16B.002 Manchester Town Hall**Observations:** A 16mm thick, firm but crushable, fine-medium grained, grey coloured mortar, with sparse hair and inclusions of coal/charcoal.**RESULTS**

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO ₂ emission	12.8	
Dolomite %D	Calcimetry and titrimetric (EDTA)	3.6	
Aggregate	Gravimetric	74.0	
Gypsum	Barium Chloride	1	
Nitrates	Titrimetric/test strips.	0.02	
Chlorides	Titrimetric/test strips.	0	
Iron Oxides (Fe₂O₃)	Test strips/Titrimetric (K ₂ Cr ₂ O ₇)	0.6	
pH of mortar sample	Indicator Strips/pH meter	11	
Mix Ratio by Mass	Parts Aggregate : Parts Binder	2.9 : 1	
Mix Ratio by Volume (if binder was lime putty)	Parts Aggregate : Parts Binder	1.7 : 1	
Mix Ratio by Volume (if binder was Hydraulic lime or cement)	Parts Aggregate : Parts Binder	2 : 1	
Active lime [Ca(OH)₂]	Titrimetric (Extracted in 10% sugar solution)	0.1	
Carbonated lime in binder (degree of Carbonation)	From %Ca(OH) ₂ in binder	99	
Cementitious Compounds	%S x 2.5	7.9	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	2.8	
Soluble Silica in Original Binder	From: %S x $\frac{(A + 1)}{B}$	14.6	
CaO in Original Binder	From CaO in mortar	53.9	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	10.4	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	-	
Cementation Index for Binder (CI)	$CI \approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	0.6	
Type of Binder or equivalent strength	Dependent on the % Soluble Silica in Binder	Moderate - Eminently hydraulic dolomitic lime (NHL3.5 - 5)	

Results of Plaster Analysis, Manchester Town Hall

A lime putty with 50% moisture by mass is considered in the calculations above. A greater percentage of moisture in the lime putty, gives a higher Aggregate : Binder ratio (by mass and/or volume)

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	RETAINED MASS (gms)	% RETAINED	% PASSING	AGGREGATE CHARACTERISTICS
5.45		0	100	
2.465		5.26	94.73	Angular Black-grey coke + iron oxides (magnetic), pozzolanic blast furnace slag material.
0.915		12.28	82.45	As above + red-orange brick fragments + off-white lithic fragments and wood fragments
0.567		7.01	75.43	As above
0.411		7.30	68.12	As above + angular clear/milky/yellow/rose quartz grains
0.14		36.84	31.28	As above
0.09		14.03	17.25	As above
<0.09		17.25	0	As above

Methodology: A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques, in addition to polarised light microscopy, are used to determine the components and characteristics of the mortar sample, as shown in the results table.

Summary of Results and Comments:	The Aggregate: is a fine - coarse grained, dark grey coloured essentially blast furnace iron slag material, which would have had a pozzolanic effect on the binder by virtue of its reaction with lime to produce calcium silicate cementitious compounds, giving added strength and set to the mortar:  Aggregate mag. x 10 The Binder: is equivalent in strength to a moderately - eminently hydraulic, dolomitic lime. It was probably an on-site hot lime mix, like the others, which usually gives a low aggregate : binder mix ratio by volume, although in this case the mix ratio is acceptable. Gypsum does not appear to be a significant proportion of the mix, but may have been added to increase the set. The Mortar: has a mix ratio by volume of 1.7 – 2 : 1 aggregate : binder.
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Date Analysed: 24/02/19**Sample:** Top Coat Wall Plaster on brick, IS.B1.16B.002 Manchester Town Hall**Observations:** A 2mm thick, off-white coloured, fine grained, hard mortar.**RESULTS**

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO ₂ emission	28.5	
Dolomite %D	Calcimetry and titrimetric (EDTA)	4.4	
Aggregate	Gravimetric	46.2	
Gypsum	Barium Chloride	16	
Nitrates	Titrimetric/test strips.	0	
Chlorides	Titrimetric/test strips.	0	
Iron Oxides (Fe ₂ O ₃)	Test strips/Titrimetric (potassium dichromate)	0.3	
pH of mortar sample	Indicator Strips/pH meter	7	
Mix Ratio if Gypsum was part Of the binder	Parts Aggregate	2.9	
	Parts Lime	1.8	
	Parts Gypsum	1	
Active lime [Ca(OH) ₂]	Titrimetric (Extracted in 10% sugar solution)	0	
Carbonated lime in binder (degree of Carbonation)	From %Ca(OH) ₂ in binder	100	
Cementitious Compounds	%S x 2.5	4.6	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	1.7	
Soluble Silica in Original Binder	From %S x $\frac{A+1}{B}$	4.1	
CaO in Original Binder	From CaO in mortar	59.6	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	24.1	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	-	
Cementation Index for Binder (CI)	CI $\approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	n/a	
Type of Binder	Dependent on the % Soluble Silica in Binder	Gypsum + feebly hydraulic dolomitic lime (NHL2)	

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	RETAINED MASS (gms)	% RETAINED	% PASSING	AGGREGATE CHARACTERISTICS
5.45		0	100	
2.465		0	100	
0.915		0	100	
0.567		1.44	98.55	Angular black coke/iron oxides + some quartz grains
0.411		11.59	86.95	As above + angular clear/milky/yellow/rose quartz grains
0.14		86.95	0	As above but mostly clear/milky/yellow/rose quartz grains
0.09		0	0	
<0.09		0	0	

Methodology: A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques, in addition to polarised light microscopy, are used to determine the components and characteristics of the mortar sample, as shown in the results table.

Summary of Results and Comments:	The Aggregate: is a mostly a light warm buff coloured, fine grained sharp silica sand, with some grey/black pozzolanic coke and iron oxides + off-white/grey lithic fragments:  Aggregate mag. x 10 The Binder: is 1 part Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) 1.8 parts Feeble - Moderately hydraulic, dolomitic lime. The Mortar: consists of 2.9 parts Aggregate : 1 part Gypsum : 1.8 parts Dolomitic lime.
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Appendix 2: Analysis sheets IS.01.102.003 – Room 102, wall**Date Analysed:** 22/02/19**Sample:** Base Coat Wall Plaster IS.01.102.003 Manchester Town Hall**Observations:** A 23 – 30mm thick, grey coloured, fine-medium grained, firm but readily crushed mortar with sparse hair and some coal/charcoal inclusions.**RESULTS**

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO ₂ emission	3.6	
Dolomite %D	Calcimetry and titrimetric (EDTA)	4.4	
Aggregate	Gravimetric	87.0	
Gypsum	Barium Chloride	1.3	
Nitrates	Titrimetric/test strips.	0	
Chlorides	Titrimetric/test strips.	0	
Iron Oxides (Fe₂O₃)	Test strips/Titrimetric (potassium dichromate)	0.6	
pH of mortar sample	Indicator Strips/pH meter	7	
Mix Ratio if Gypsum was part Of the binder	Parts Aggregate	66	
	Parts Lime	2.7	
	Parts Gypsum	1	
Active lime [Ca(OH)₂]	Titrimetric (Extracted in 10% sugar solution)	0	
Carbonated lime in binder (degree of Carbonation)	From %Ca(OH) ₂ in binder	100	
Cementitious Compounds	%S x 2.5	3.1	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	1.1	
Soluble Silica in Original Binder	From %S x $\frac{A}{B} + 1$	11.5	
CaO in Original Binder	From CaO in mortar	37.8	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	3.6	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	-	
Cementation Index for Binder (CI)	$CI \approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	0.34	
Type of Binder	Dependent on the % Soluble Silica in Binder	Moderately hydraulic dolomitic lime (NHL3.5) + gypsum	

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	RETAINED MASS (gms)	% RETAINED	% PASSING	AGGREGATE CHARACTERISTICS
5.45		0	100	
2.465		0	100	
0.915		0.15	99.84	Angular black coke and iron xides + off-white/grey lithic fragments
0.567		1.86	97.98	As above + angular clear/milky/yellow/rose quartz grains
0.411		7.75	90.23	As above but mostly angular clear/milky/yellow/rose quartz grains
0.14		67.90	22.32	As above
0.09		11.47	10.85	As above
<0.09		10.85	0	As above

Methodology: A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques, in addition to polarised light microscopy, are used to determine the components and characteristics of the mortar sample, as shown in the results table.

Summary of Results and Comments:	The Aggregate: is a light grey-brown coloured, fine-medium grained mostly sharp silica sand (warm buff coloured) + a pozzolanic blast furnace iron slag material:
	 Aggregate mag. x 10 The Binder: is 1 part Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) + 2.7 parts Moderately hydraulic, dolomitic lime. The Mortar: consists of 66 parts Aggregate : 1 part Gypsum : 2.7 parts Dolomitic lime.

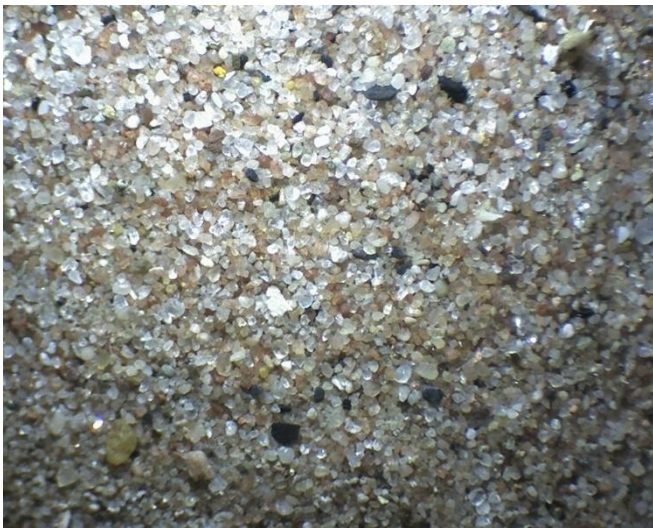
Date Analysed: 22/02/19**Sample:** Top Coat Wall Plaster IS.01.102.003 Manchester Town Hall**Observations:** A 2 - 3mm thick, off-white coloured, quite hard, fine grained mortar.**RESULTS**

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO ₂ emission	23.0	
Dolomite %D	Calcimetry and titrimetric (EDTA)	5.5	
Aggregate	Gravimetric	65.1	
Gypsum	Barium Chloride	1	
Nitrates	Titrimetric/test strips.	0	
Chlorides	Titrimetric/test strips.	0	
Iron Oxides (Fe₂O₃)	Test strips/Titrimetric (K ₂ Cr ₂ O ₇)	0.3	
pH of mortar sample	Indicator Strips/pH meter	7	
Mix Ratio by Mass	Parts Aggregate : Parts Binder	1.9 : 1	
Mix Ratio by Volume (if binder was lime putty)	Parts Aggregate : Parts Binder	1.1 : 1	
Mix Ratio by Volume (if binder was Hydraulic lime or cement)	Parts Aggregate : Parts Binder	1.3 : 1	
Active lime [Ca(OH)₂]	Titrimetric (Extracted in 10% sugar solution)	0	
Carbonated lime in binder (degree of Carbonation)	From %Ca(OH) ₂ in binder	100	
Cementitious Compounds	%S x 2.5	5.1	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	1.8	
Soluble Silica in Original Binder	From: %S x $\frac{A+1}{B}$	6.95	
CaO in Original Binder	From CaO in mortar	57.7	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	15.1	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	-	
Cementation Index for Binder (CI)	CI $\approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	0.24	
Type of Binder or equivalent strength	Dependent on the % Soluble Silica in Binder	Moderately hydraulic dolomitic lime (NHL3.5)	

A lime putty with 50% moisture by mass is considered in the calculations above. A greater percentage of moisture in the lime putty, gives a higher Aggregate : Binder ratio (by mass and/or volume)

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	RETAINED MASS (gms)	% RETAINED	% PASSING	AGGREGATE CHARACTERISTICS
5.45		0	100	
2.465		0	100	
0.915		0	100	
0.567		0.28	99.71	Angular black coke + iron oxides + clear angular/sub-rounded quartz grains
0.411		2.31	97.39	As above but mostly angular/sub-rounded clear/milky/yellow/quartz grains
0.14		55.07	42.31	Mostly angular/sub-rounded clear/milky/yellow/quartz grains
0.09		30.72	11.59	As above
<0.09		11.59	0	As above

Methodology: A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques, in addition to polarised light microscopy, are used to determine the components and characteristics of the mortar sample, as shown in the results table.

Summary of Results and Comments:	The Aggregate: is mostly a light warm buff coloured, fine grained sharp silica sand, with some grey/black coke and iron oxides (pozzolanic slag) + off-white/grey lithic fragments:  Aggregate mag. x 10 The Binder: is equivalent in strength to a moderately hydraulic, dolomitic lime. It was probably an on-site hot lime mix, which usually gives a characteristically low aggregate : binder mix ratio by volume. The small amount of slag material may have given the mortar a degree of hardness and set, by virtue of its reaction with the free lime content, producing cementitious calcium silicate compounds. The Mortar: has a mix ratio by volume of 1.1 – 1.3 : 1 aggregate : binder.
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Appendix 3: Analysis sheets IS.02.216.006 – Room 216, wall**Date Analysed:** 23/02/19**Sample:** Base Coat Wall Plaster, IS.02.216.006 Manchester Town Hall**Observations:** A 28mm thick, light - mid grey coloured, quite hard mortar, fine – medium grained with inclusions vof coal/charcoal and sparse hair.**RESULTS**

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO ₂ emission	9.3	
Dolomite %D	Calcimetry and titrimetric (EDTA)	5.7	
Aggregate	Gravimetric	39.7	
Gypsum	Barium Chloride	30.2	
Nitrates	Titrimetric/test strips.	0.02	
Chlorides	Titrimetric/test strips.	0	
Iron Oxides (Fe₂O₃)	Test strips/Titrimetric (potassium dichromate)	0.3	
pH of mortar sample	Indicator Strips/pH meter	11	
Mix Ratio if Gypsum was part Of the binder	Parts Aggregate	4.2	
	Parts Lime	1	
	Parts Gypsum	3.2	
Active lime [Ca(OH)₂]	Titrimetric (Extracted in 10% sugar solution)	0.1	
Carbonated lime in binder (degree of Carbonation)	From %Ca(OH) ₂ in binder	99.6	
Cementitious Compounds	%S x 2.5	15.1	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	5.4	
Soluble Silica in Original Binder	From %S x $\frac{(A + 1)}{B}$	11.8	
CaO in Original Binder	From CaO in mortar	50.4	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	23	
Aluminium Oxide in Blnder	Gravimetric (using Oxine)	-	
Cementation Index for Binder (CI)	$CI \approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	0.6	
Type of Binder	Dependent on the % Soluble Silica in Binder	Gypsum + Moderately hydraulic dolomitic lime (NHL3.5)	

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	RETAINED MASS (gms)	% RETAINED	% PASSING	AGGREGATE CHARACTERISTICS
5.45		0	100	
2.465		0	100	
0.915		7.56	92.43	Angular black-grey coke + iron oxides (magnetic), off-white lithic fragments and red brick fragments
0.567		11.76	80.67	As above + some angular clear/yellow/milky/rose quartz grains
0.411		11.76	68.90	As above
0.14		39.49	29.41	As above but mostly angular clear/yellow/milky/rose quartz grains
0.09		12.60	16.80	As above
<0.09		16.80	0	As above

Methodology: A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques, in addition to polarised light microscopy, are used to determine the components and characteristics of the mortar sample, as shown in the results table.

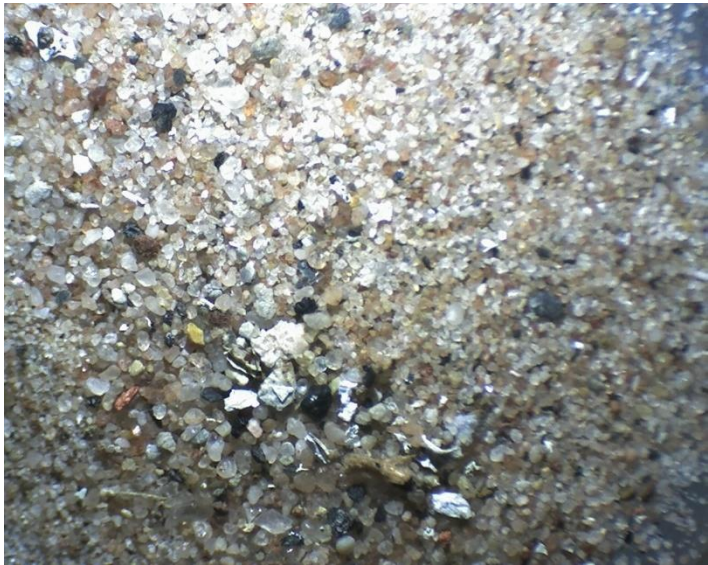
Summary of Results and Comments:	The Aggregate: is a light grey-brown coloured, fine-medium grained mostly sharp silica sand (warm buff coloured) + a pozzolanic blast furnace iron slag material:
	 Aggregate mag. x 10 The Binder: is 3.2 parts Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) + 1 part Moderately hydraulic, dolomitic lime. The Mortar: consists of 4.2 parts Aggregate : 3.2 parts Gypsum : 1 part Dolomitic lime.

Date Analysed: 22/02/19**Sample:** Top Coat Wall Plaster, IS.02.216.006, Manchester Town Hall**Observations:** A hard, light grey coloured, fine grained, 2mm thick mortar.**RESULTS**

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO ₂ emission	17.3	
Dolomite %D	Calcimetry and titrimetric (EDTA)	11.5	
Aggregate	Gravimetric	29.3	
Gypsum	Barium Chloride	32	
Nitrates	Titrimetric/test strips.	0	
Chlorides	Titrimetric/test strips.	0	
Iron Oxides (Fe ₂ O ₃)	Test strips/Titrimetric (potassium dichromate)	0.3	
pH of mortar sample	Indicator Strips/pH meter	11	
Mix Ratio if Gypsum was part Of the binder	Parts Aggregate	1.7	
	Parts Lime	1	
	Parts Gypsum	1.9	
Active lime [Ca(OH) ₂]	Titrimetric (Extracted in 10% sugar solution)	0	
Carbonated lime in binder (degree of Carbonation)	From %Ca(OH) ₂ in binder	100	
Cementitious Compounds	%S x 2.5	9.4	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	3.3	
Soluble Silica in Original Binder	From %S x $\frac{(A + 1)}{B}$	6.3	
CaO in Original Binder	From CaO in mortar	48.9	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	26.0	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	-	
Cementation Index for Binder (CI)	CI $\approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	0.2	
Type of Binder	Dependent on the % Soluble Silica in Binder	Gypsum + Moderately hydraulic dolomitic lime	

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	RETAINED MASS (gms)	% RETAINED	% PASSING	AGGREGATE CHARACTERISTICS
5.45		0	100	
2.465		0	100	
0.915		0	100	
0.567		0	100	
0.411		2.63	97.36	Angular black coke/iron oxides + clear/yellow/rose quartz grains + red brick fragments
0.14		52.63	44.73	Mostly angular clear/milky/yellow/rose quartz grains
0.09		34.21	10.52	As above
<0.09		10.52	0	As above

Methodology: A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques, in addition to polarised light microscopy, are used to determine the components and characteristics of the mortar sample, as shown in the results table.

Summary of Results and Comments:	The Aggregate: is mostly a light warm buff coloured, fine grained sharp silica sand, with some grey/black coke and iron oxides (pozzolanic slag) + off-white/grey lithic fragments:
	 Aggregate mag. x 10 The Binder: is 1.9 parts Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) 1 part Moderately hydraulic, dolomitic lime. The Mortar: consists of 1.7 parts Aggregate : 1.9 parts Gypsum : 1 part Dolomitic lime.

Appendix 4: Analysis sheets IS.02.216.012 – Room 216, ceiling beam**Date Analysed:** 21/02/19**Sample:** IS.02.216.012 Base Coat Ceiling plaster, Manchester Town Hall**Observations:** A 13mm thick, mid-grey coloured, fine-medium grained, firm but easily crushable mortar with sparse hair and occasional inclusions of black coal/charcoal.**RESULTS**

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO ₂ emission	4.9	
Dolomite %D	Calcimetry and titrimetric (EDTA)	3.4	
Aggregate	Gravimetric	60.7	
Gypsum	Barium Chloride	20.7	
Nitrates	Titrimetric/test strips.	0	
Chlorides	Titrimetric/test strips.	0	
Iron Oxides (Fe₂O₃)	Test strips/Titrimetric (potassium dichromate)	0.6	
pH of mortar sample	Indicator Strips/pH meter	11	
Mix Ratio if Gypsum was part Of the binder	Parts Aggregate	11.8	
	Parts Lime	1	
	Parts Gypsum	4	
Active lime [Ca(OH)₂]	Titrimetric (Extracted in 10% sugar solution)	0.2	
Carbonated lime in binder (degree of Carbonation)	From %Ca(OH) ₂ in binder	98.6	
Cementitious Compounds	%S x 2.5	9.6	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	3.4	
Soluble Silica in Original Binder	From %S x $\frac{A}{B} + 1$	11.6	
CaO in Original Binder	From CaO in mortar	50.0	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	14.7	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	-	
Cementation Index for Binder (CI)	CI $\approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	0.6	
Type of Binder	Dependent on the % Soluble Silica in Binder	Gypsum + Moderately hydraulic dolomitic lime (NHL3.5)	

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	RETAINED MASS (gms)	% RETAINED	% PASSING	AGGREGATE CHARACTERISTICS
5.45		0	100	
2.465		0	100	
0.915		0.22	99.77	Angular black coke + off-white lithic fragments
0.567		3.61	96.16	As above + iron oxides (magnetic) + angular/sub angular clear/milky/yellow/rose quartz grains
0.411		4.96	91.19	As above but mostly angular/sub angular clear/milky/yellow/rose quartz grains
0.14		59.14	32.05	As above
0.09		17.60	14.44	As above
<0.09		14.44	0	As above

Methodology: A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques, in addition to polarised light microscopy, are used to determine the components and characteristics of the mortar sample, as shown in the results table.

Summary of Results and Comments:	The Aggregate: is a light grey-brown coloured, fine-medium grained mostly sharp silica sand (warm buff coloured) + a pozzolanic blast furnace iron slag material:  Aggregate mag. x 10 The Binder: is 4 parts Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) + 1 part Moderately hydraulic, dolomitic lime. The Mortar: consists of 11.8 parts Aggregate : 4 parts Gypsum : 1 part Dolomitic lime.
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Date Analysed: 21/02/19**Sample:** Top Coat Ceiling Plaster, IS.02.216.012, Manchester Town Hall**Observations:** An 8mm thick, off-white coloured, fine grained, quite hard mortar.**RESULTS**

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO ₂ emission	25.4	
Dolomite %D	Calcimetry and titrimetric (EDTA)	3.9	
Aggregate	Gravimetric	1.1	
Gypsum	Barium Chloride	60	
Nitrates	Titrimetric/test strips.	0	
Chlorides	Titrimetric/test strips.	0	
Iron Oxides (Fe₂O₃)	Test strips/Titrimetric (potassium dichromate)	0.2	
pH of mortar sample	Indicator Strips/pH meter	0	
Mix Ratio if Gypsum was part Of the binder	Parts Aggregate	0.05	
	Parts Lime	1	
	Parts Gypsum	2.4	
Active lime [Ca(OH)₂]	Titrimetric (Extracted in 10% sugar solution)	0	
Carbonated lime in binder (degree of Carbonation)	From %Ca(OH) ₂ in binder	100	
Cementitious Compounds	%S x 2.5	n/a	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	n/a	
Soluble Silica in Original Binder	From %S x $\frac{(A + 1)}{B}$	n/a	
CaO in Original Binder	From CaO in mortar	56.1	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	42.0	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	-	
Cementation Index for Binder (CI)	CI $\approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	n/a	
Type of Binder	Dependent on the % Soluble Silica in Binder	Gypsum + dolomitic hydraulic lime.	

A lime putty with 50% moisture by mass is considered in the calculations above. A greater percentage of moisture in the lime putty, gives a higher Aggregate : Binder ratio (by mass and/or volume)

Methodology: A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques, in addition to polarised light microscopy, are used to

determine the components and characteristics of the mortar sample, as shown in the results table.

Summary of Results and Comments:	The Aggregate: There is negligible aggregate content in the sample analysed. The Binder: is 2.4 parts Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) 1 part Moderately hydraulic, dolomitic lime. The Mortar: consists of 0.05 parts Aggregate : 2.4 parts Gypsum : 1 part Dolomitic lime.
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Appendix 5: Analysis sheets IS.04.P-430.001 – Room P-430, wall**Date Analysed:** 22/02/19**Sample:** Base Coat Wall Plaster, IS.04.P- 430.001 Manchester Town Hall**Observations:** A 20mm thick, fine-coarse grained, dark-grey coloured, quite firm but crushable, hair mortar, with inclusions of black-grey coke and iron oxides.**RESULTS**

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO ₂ emission	7.0	
Dolomite %D	Calcimetry and titrimetric (EDTA)	4.6	
Aggregate	Gravimetric	79.4	
Gypsum	Barium Chloride	0.97	
Nitrates	Titrimetric/test strips.	0.01	
Chlorides	Titrimetric/test strips.	0	
Iron Oxides (Fe₂O₃)	Test strips/Titrimetric (potassium dichromate)	0.6	
pH of mortar sample	Indicator Strips/pH meter	11	
Mix Ratio if Gypsum was part Of the binder	Parts Aggregate	81.8	
	Parts Lime	7.3	
	Parts Gypsum	1	
Active lime [Ca(OH)₂]	Titrimetric (Extracted in 10% sugar solution)	0.06	
Carbonated lime in binder (degree of Carbonation)	From %Ca(OH) ₂ in binder	98.9	
Cementitious Compounds	%S x 2.5	7.2	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	2.6	
Soluble Silica in Original Binder	From %S x $\frac{(A + 1)}{B}$	17.0	
CaO in Original Binder	From CaO in mortar	45.6	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	6.9	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	-	
Cementation Index for Binder (CI)	$CI \approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	0.6	
Type of Binder	Dependent on the % Soluble Silica in Binder	Eminently hydraulic dolomitic lime (NHL5) + Gypsum	

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	RETAINED MASS (gms)	% RETAINED	% PASSING	AGGREGATE CHARACTERISTICS
5.45		0	100	
2.465		0.56	99.43	Angular black-grey coke + iron oxides (some magnetic), Iron blast furnace slag material
0.915		1.31	98.1	As above + black brown off-white iron compounds and amorphous silicates
0.567		0.58	97.54	As above + wood fragments
0.411		0.58	96.96	As above + angular clear/milky/yellow/rose quartz grains
0.14		2.53	94.42	As above
0.09		0.74	93.67	As above
<0.09		93.67	0	As above

Methodology: A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques, in addition to polarised light microscopy, are used to determine the components and characteristics of the mortar sample, as shown in the results table.

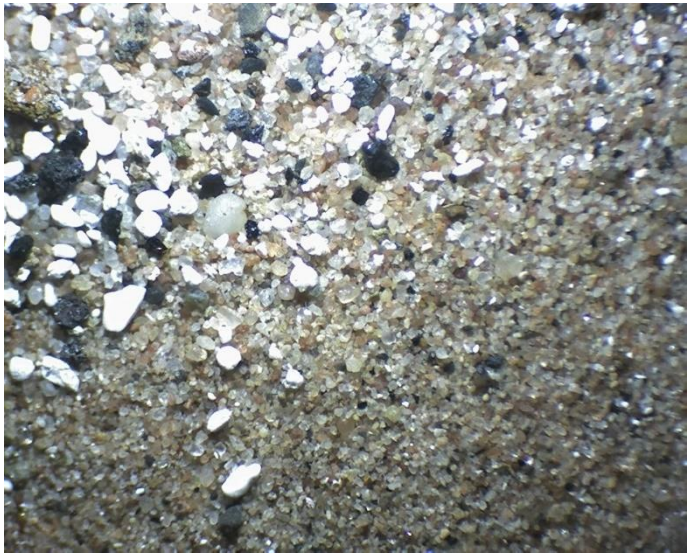
Summary of Results and Comments:	The Aggregate: is a fine - coarse grained, dark grey coloured essentially blast furnace iron slag material, which would have had a pozzolanic effect on the binder by virtue of its reaction with lime to produce calcium silicate cementitious compounds, giving added strength and set to the mortar:  Aggregate mag. x 10 The Binder: is 1 part Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) + 7.3 parts Moderately hydraulic, dolomitic lime. The Mortar: consists of 81.8 parts Aggregate : 1 part Gypsum : 7.3 parts Dolomitic lime.
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Date Analysed: 21/02/19**Sample:** Top Coat Wall Plaster, IS.04.P-430.001 Manchester Town Hall**Observations:** A 2mm thick, grey coloured, fine grained, quite firm but easily crushed mortar, with sparse hair and coal/charcoal inclusions.**RESULTS**

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO ₂ emission	10.0	
Dolomite %D	Calcimetry and titrimetric (EDTA)	3.7	
Aggregate	Gravimetric	24.1	
Gypsum	Barium Chloride	56	
Nitrates	Titrimetric/test strips.	0.1	
Chlorides	Titrimetric/test strips.	0	
Iron Oxides (Fe ₂ O ₃)	Test strips/Titrimetric (potassium dichromate)	0.3	
pH of mortar sample	Indicator Strips/pH meter	11	
Mix Ratio if Gypsum was part Of the binder	Parts Aggregate	2.4	
	Parts Lime	1	
	Parts Gypsum	5.6	
Active lime [Ca(OH) ₂]	Titrimetric (Extracted in 10% sugar solution)	0	
Carbonated lime in binder (degree of Carbonation)	From %Ca(OH) ₂ in binder	100	
Cementitious Compounds	%S x 2.5	n/a	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	n/a	
Soluble Silica in Original Binder	From %S x $\frac{(A + 1)}{B}$	n/a	
CaO in Original Binder	From CaO in mortar	53.4	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	30.6	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	-	
Cementation Index for Binder (CI)	CI $\approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	n/a	
Type of Binder	Dependent on the % Soluble Silica in Binder	Gypsum + hydraulic dolomitic lime	

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	RETAINED MASS (gms)	% RETAINED	% PASSING	AGGREGATE CHARACTERISTICS
5.45		0	100	
2.465		0	100	
0.915		0	100	
0.567		0.418	99.58	Angular black coke+ iron oxides + off-white lithic grains + some quartz grains
0.411		1.67	97.90	As above
0.14		40.16	57.74	As above but mostly angular clear/milky/yellow/rose quartz grains
0.09		29.28	28.45	As above
<0.09		28.45	0	As above

Methodology: A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques, in addition to polarised light microscopy, are used to determine the components and characteristics of the mortar sample, as shown in the results table.

Summary of Results and Comments:	The Aggregate: is mostly a light warm buff coloured, fine grained sharp silica sand, with some grey/black coke and iron oxides (pozzolanic slag) + off-white/grey lithic fragments:
	 Aggregate mag. x 10 The Binder: is 5.6 parts Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) 1 part Moderately hydraulic, dolomitic lime. The Mortar: consists of 2.4 parts Aggregate : 5.6 parts Gypsum : 1 part Dolomitic lime.

Appendix 6: Analysis sheets IS.06.606.004 – Room 606, wall**Date Analysed:** 26/02/19**Sample:** Base Coat Plaster (under ceiling), IS.06.606.004 Manchester Town Hall**Observations:** An 18mm thick, mid-grey coloured, fine-coarse grained, quite firm but easily crushed mortar, with sparse and some inclusions of coal/charcoal.**RESULTS**

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO ₂ emission	22.5	
Dolomite %D	Calcimetry and titrimetric (EDTA)	2.8	
Aggregate	Gravimetric	58.3	
Gypsum	Barium Chloride	9.7	
Nitrates	Titrimetric/test strips.	0	
Chlorides	Titrimetric/test strips.	0	
Iron Oxides (Fe₂O₃)	Test strips/Titrimetric (potassium dichromate)	0.5	
pH of mortar sample	Indicator Strips/pH meter	7	
Mix Ratio if Gypsum was part Of the binder	Parts Aggregate	6	
	Parts Lime	2.3	
	Parts Gypsum	1	
Active lime [Ca(OH)₂]	Titrimetric (Extracted in 10% sugar solution)	0	
Carbonated lime in binder (degree of Carbonation)	From %Ca(OH) ₂ in binder	100	
Cementitious Compounds	%S x 2.5	6.2	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	2.2	
Soluble Silica in Original Binder	From %S x $\frac{(A + 1)}{B}$	7.1	
CaO in Original Binder	From CaO in mortar	59.9	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	18.7	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	-	
Cementation Index for Binder (CI)	CI $\approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	0.3	
Type of Binder	Dependent on the % Soluble Silica in Binder	Moderately hydraulic lime (NHL3.5) + gypsum	

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	RETAINED MASS (gms)	% RETAINED	% PASSING	AGGREGATE CHARACTERISTICS
5.45		0	100	
2.465		0	100	
0.915		4.36	95.63	Angular black-grey coke + iron oxides (magnetic) + red-orange brick fragments, off-white lithic fragments
0.567		3.57	92.06	As above + angular clear/milky/yellow/rose quartz grains + wood fragments
0.411		7.14	84.92	As above
0.14		48.41	36.50	As above but mostly angular clear/milky/yellow/rose quartz grains + wood fragments
0.09		16.66	19.84	As above
<0.09		19.84		As above

Methodology: A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques, in addition to polarised light microscopy, are used to determine the components and characteristics of the mortar sample, as shown in the results table.

Summary of Results and Comments:	The Aggregate: is a light grey-brown coloured, fine-coarse grained mostly sharp silica sand (warm buff coloured) + a pozzolanic blast furnace iron slag material.  Aggregate mag. x 10 The Binder: is 1 part Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) + 2.3 parts Moderately hydraulic, dolomitic lime. The Mortar: consists of 6 parts Aggregate : 1 part Gypsum : 2.3 parts Dolomitic lime.
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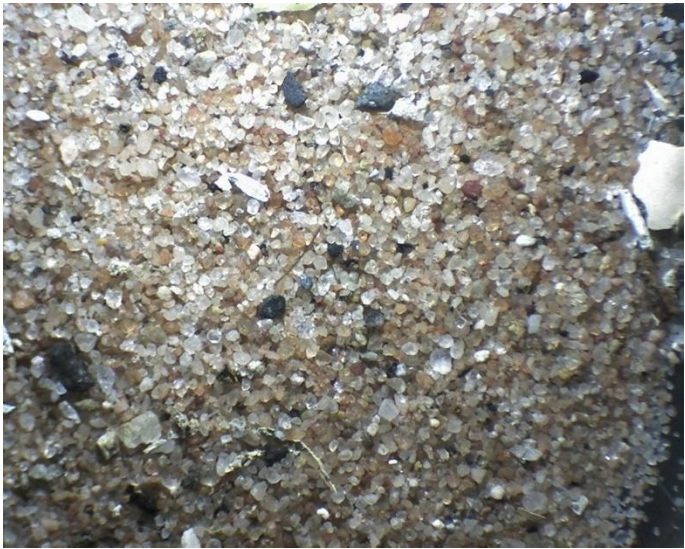
Date Analysed: 21/02/19**Sample:** Top Coat Plaster (under ceiling), IS.06.606.004 Manchester Town Hall**Observations** A 2mm thick, hard, light grey coloured, fine grained mortar.**RESULTS**

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO ₂ emission	31.9	
Dolomite %D	Calcimetry and titrimetric (EDTA)	5.3	
Aggregate	Gravimetric	54.3	
Gypsum	Barium Chloride	2	
Nitrates	Titrimetric/test strips.	0	
Chlorides	Titrimetric/test strips.	0	
Iron Oxides (Fe₂O₃)	Test strips/Titrimetric (K ₂ Cr ₂ O ₇)	0.3	
pH of mortar sample	Indicator Strips/pH meter	7	
Mix Ratio by Mass	Parts Aggregate : Parts Binder	1.2 : 1	
Mix Ratio by Volume (if binder was lime putty)	Parts Aggregate : Parts Binder	0.7 : 1	
Mix Ratio by Volume (if binder was Hydraulic lime or cement)	Parts Aggregate : Parts Binder	0.8 : 1	
Active lime [Ca(OH)₂]	Titrimetric (Extracted in 10% sugar solution)	0	
Carbonated lime in binder (degree of Carbonation)	From %Ca(OH) ₂ in binder	100	
Cementitious Compounds	%S x 2.5	6.1	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	2.2	
Soluble Silica in Original Binder	From: %S x $\frac{(A + 1)}{B}$	6.4	
CaO in Original Binder	From CaO in mortar	60.7	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	20.8	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	-	
Cementation Index for Binder (CI)	$CI \approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	0.2	
Type of Binder or equivalent strength	Dependent on the % Soluble Silica in Binder	Moderately hydraulic dolomitic lime (NHL3.5)	

A lime putty with 50% moisture by mass is considered in the calculations above. A greater percentage of moisture in the lime putty, gives a higher Aggregate : Binder ratio (by mass and/or volume)

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	RETAINED MASS (gms)	% RETAINED	% PASSING	AGGREGATE CHARACTERISTICS
5.45		0	100	
2.465		0	100	
0.915		0	100	
0.567		1.09	98.90	Angular black coke/iron oxides + some quartz grains
0.411		0.54	98.36	As above + more quartz grains
0.14		36.06	62.29	Mostly angular clear/milky/yellow/rose quartz grains
0.09		26.22	36.06	As above
<0.09		36.06	0	As above

Methodology: A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques, in addition to polarised light microscopy, are used to determine the components and characteristics of the mortar sample, as shown in the results table.

Summary of Results and Comments:	The Aggregate: is mostly a light warm buff coloured, fine grained sharp silica sand, with some grey/black coke and iron oxides (pozzolanic slag) + off-white/grey lithic fragments:  Aggregate mag. x 10 The Binder: is equivalent in strength to a moderately hydraulic, dolomitic lime. It was probably an on-site hot lime mix, which usually gives a characteristically low aggregate : binder mix ratio by volume. The small amount of slag material may have given the mortar a degree of hardness and set, by virtue of its reaction with the free lime content, producing cementitious calcium silicate compounds. The Mortar: has a mix ratio by volume of 0.7 – 0.8 : 1 aggregate : binder.
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Appendix 7: IS.06.606.007 – Room 606, wall

Date Analysed: 26/02/19

Sample: Base Coat Wall Plaster, IS.06.606.007 Manchester Town Hall

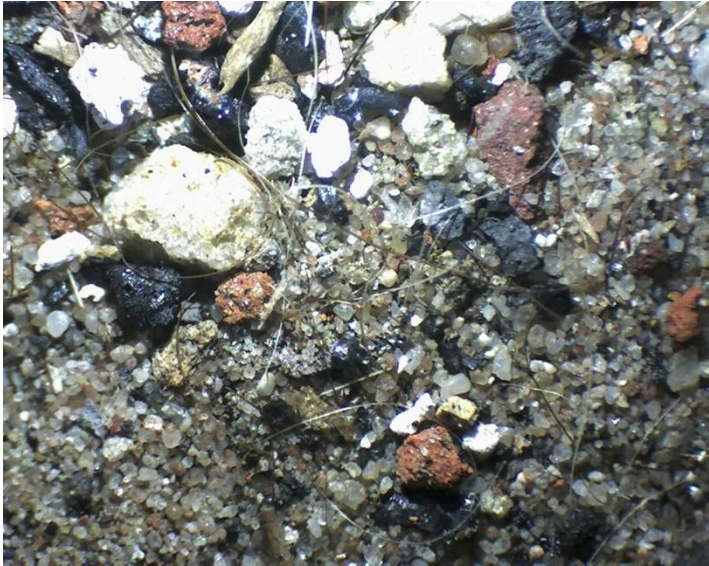
Observations: A 20mm thick, grey coloured, firm but crushable, fine - medium grained mortar with significant hair (compared with other base coats) and inclusions of coal/charcoal, off-white carbonated lime and wood fragments.

RESULTS

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO ₂ emission	20.4	
Dolomite %D	Calcimetry and titrimetric (EDTA)	0.72	
Aggregate	Gravimetric	64.1	
Gypsum	Barium Chloride	8.4	
Nitrates	Titrimetric/test strips.	0.02	
Chlorides	Titrimetric/test strips.	0	
Iron Oxides (Fe₂O₃)	Test strips/Titrimetric (potassium dichromate)	0.6	
pH of mortar sample	Indicator Strips/pH meter	10	
Mix Ratio if Gypsum was part Of the binder	Parts Aggregate	7.6	
	Parts Lime	2.4	
	Parts Gypsum	1	
Active lime [Ca(OH)₂]	Titrimetric (Extracted in 10% sugar solution)	0.004	
Carbonated lime in binder (degree of Carbonation)	From %Ca(OH) ₂ in binder	99.9	
Cementitious Compounds	%S x 2.5	5.8	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	2.1	
Soluble Silica in Original Binder	From %S x $\frac{A+1}{B}$	7.7	
CaO in Original Binder	From CaO in mortar	62.8	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	16.9	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	-	
Cementation Index for Binder (CI)	$CI \approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	0.4	
Type of Binder	Dependent on the % Soluble Silica in Binder	Moderately hydraulic dolomitic lime (NHL3.5) + gypsum	

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	RETAINED MASS (gms)	% RETAINED	% PASSING	AGGREGATE CHARACTERISTICS
5.45		0	100	
2.465		3.53	96.46	Angular off-white amorphous silicates + red-brown iron compounds
0.915		8.69	87.77	Angular black-grey coke and iron oxides (magnetic), red brick dust, off-white/grey lithic fragments + wood
0.567		5.70	82.06	As above
0.411		6.52	75.54	As above + angular clear/milky/yellow/rose quartz grains
0.14		47.82	27.71	As above
0.09		12.5	15.21	As above
<0.09		15.21	0	As above

Methodology: A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques, in addition to polarised light microscopy, are used to determine the components and characteristics of the mortar sample, as shown in the results table.

Summary of Results and Comments:	The Aggregate: is a fine - coarse grained, grey-brown coloured essentially blast furnace iron slag material, which would have had a pozzolanic effect on the binder by virtue of its reaction with lime to produce calcium silicate cementitious compounds, giving added strength and set to the mortar:  Aggregate mag. x 10 The Binder: is 1 part Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) + 2.4 parts Moderately hydraulic, dolomitic lime. The Mortar: consists of 7.6 parts Aggregate : 1 part Gypsum : 2.4 parts Dolomitic lime.
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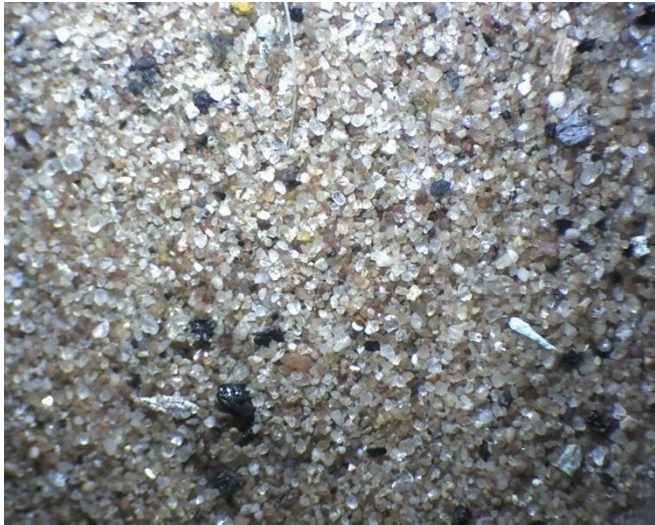
Date Analysed: 25/02/19**Sample:** Top Coat Wall Plaster, IS.06.606.007 Manchester Town Hall**Observations:** A 1.5 - 2mm thick, off-white coloured, hard, fine grained mortar.**RESULTS**

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO ₂ emission	34.5	
Dolomite %D	Calcimetry and titrimetric (EDTA)	6.0	
Aggregate	Gravimetric	55.4	
Gypsum	Barium Chloride	1	
Nitrates	Titrimetric/test strips.	0.016	
Chlorides	Titrimetric/test strips.	0	
Iron Oxides (Fe₂O₃)	Test strips/Titrimetric (K ₂ Cr ₂ O ₇)	0.3	
pH of mortar sample	Indicator Strips/pH meter	11	
Mix Ratio by Mass	Parts Aggregate : Parts Binder	1.3 : 1	
Mix Ratio by Volume (if binder was lime putty)	Parts Aggregate : Parts Binder	0.7 : 1	
Mix Ratio by Volume (if binder was Hydraulic lime or cement)	Parts Aggregate : Parts Binder	0.9 : 1	
Active lime [Ca(OH)₂]	Titrimetric (Extracted in 10% sugar solution)	0.03	
Carbonated lime in binder (degree of Carbonation)	From %Ca(OH) ₂ in binder	99.8	
Cementitious Compounds	%S x 2.5	2.7	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	0.95	
Soluble Silica in Original Binder	From: %S x $\frac{A+1}{B}$	2.8	
CaO in Original Binder	From CaO in mortar	61.8	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	20.6	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	-	
Cementation Index for Binder (CI)	$CI \approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	0.09	
Type of Binder or equivalent strength	Dependent on the % Soluble Silica in Binder	Feebly Hydraulic dolomitic lime (NHL1)	

A lime putty with 50% moisture by mass is considered in the calculations above. A greater percentage of moisture in the lime putty, gives a higher Aggregate : Binder ratio (by mass and/or volume)

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	RETAINED MASS (gms)	% RETAINED	% PASSING	AGGREGATE CHARACTERISTICS
5.45		0	100	
2.465		0	100	
0.915		0	100	
0.567		0.66	99.33	Angular black coke and iron oxides + occasional quartz grains and wood fragments
0.411		2	97.33	As above + angular clear/milky/yellow/rose quartz grains
0.14		52	45.33	Mostly angular clear/milky/yellow/rose quartz grains
0.09		32.66	12.66	As above
<0.09		12.66	0	As above

Methodology: A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques, in addition to polarised light microscopy, are used to determine the components and characteristics of the mortar sample, as shown in the results table.

Summary of Results and Comments:	The Aggregate: is a mostly a light warm buff coloured, fine grained sharp silica sand, with some grey/black pozzolanic coke and iron oxides + off-white/grey lithic fragments:
	 Aggregate mag. x 10 The Binder: is equivalent in strength to a feebly hydraulic, dolomitic lime. It was probably an on-site hot lime mix, which usually gives a low aggregate : binder mix ratio by volume. The Mortar: has a mix ratio by volume of 0.7 – 0.9 : 1 aggregate : binder.

Appendix 8: IS.06.606.018 – Room 606, ceiling**Date Analysed:** 25/02/19**Sample:** Base Coat Ceiling Plaster, IS.06.606.018 Manchester Town Hall**Observations:** A 30 – 40mm thick, light grey coloured, fine - coarse grained, firm but crushable mortar with hair and inclusions of coal/charcoal, off-white carbonated lime and wood fragments.**RESULTS**

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO ₂ emission	22.6	
Dolomite %D	Calcimetry and titrimetric (EDTA)	Detected	
Aggregate	Gravimetric	55.9	
Gypsum	Barium Chloride	11.8	
Nitrates	Titrimetric/test strips.	0	
Chlorides	Titrimetric/test strips.	0	
Iron Oxides (Fe₂O₃)	Test strips/Titrimetric (potassium dichromate)	0.5	
pH of mortar sample	Indicator Strips/pH meter	10	
Mix Ratio if Gypsum was part Of the binder	Parts Aggregate	4.8	
	Parts Lime	2	
	Parts Gypsum	1	
Active lime [Ca(OH)₂]	Titrimetric (Extracted in 10% sugar solution)	0.003	
Carbonated lime in binder (degree of Carbonation)	From %Ca(OH) ₂ in binder	99.9	
Cementitious Compounds	%S x 2.5	9.2	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	3.2	
Soluble Silica in Original Binder	From %S x ($\frac{A}{B} + 1$)	9.9	
CaO in Original Binder	From CaO in mortar	62.6	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	20.7	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	-	
Cementation Index for Binder (CI)	CI $\approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	n/a	
Type of Binder	Dependent on the % Soluble Silica in Binder	Moderately hydraulic dolomitic lime (NHL3.5) + gypsum	

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	RETAINED MASS (gms)	% RETAINED	% PASSING	AGGREGATE CHARACTERISTICS
5.45		0	100	
2.465		0	100	
0.915		6.56	93.43	Angular red-orange brick dust + black-grey coke and iron oxides + some off-white lithic fragments
0.567		7.33	86.10	As above + wood fragments
0.411		7.72	78.37	As above + angular clear/milky/yellow/rose quartz grains
0.14		42.85	35.52	As above but mostly angular clear/milky/yellow/rose quartz grains
0.09		13.89	21.62	As above
<0.09		21.62	0	As above

Methodology: A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques, in addition to polarised light microscopy, are used to determine the components and characteristics of the mortar sample, as shown in the results table.

Summary of Results and Comments:	The Aggregate: is a light grey-brown coloured, fine-coarse grained mostly sharp silica sand (warm buff coloured) + a pozzolanic blast furnace iron slag material:
	 Aggregate mag. x 10 The Binder: is 1 part Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) + 2 parts Moderately hydraulic, dolomitic lime. The Mortar: consists of 4.8 parts Aggregate : 1 part Gypsum : 4.1 parts Dolomitic lime.

Date Analysed: 26/02/19**Sample:** Top Coat Ceiling Plaster, IS.06.606.018 Manchester Town Hall**Observations:** A 1 - 2mm thick, hard, off-white coloured, fine grained mortar.**RESULTS**

	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO ₂ emission	46.9	
Dolomite %D	Calcimetry and titrimetric (EDTA)	13.3	
Aggregate	Gravimetric	4.2	
Gypsum	Barium Chloride	29	
Nitrates	Titrimetric/test strips.	0	
Chlorides	Titrimetric/test strips.	0	
Iron Oxides (Fe₂O₃)	Test strips/Titrimetric (potassium dichromate)	0.3	
pH of mortar sample	Indicator Strips/pH meter	8	
Mix Ratio if Gypsum was part Of the binder	Parts Aggregate	0.14	
	Parts Lime	1.6	
	Parts Gypsum	1	
Active lime [Ca(OH)₂]	Titrimetric (Extracted in 10% sugar solution)	0	
Carbonated lime in binder (degree of Carbonation)	From %Ca(OH) ₂ in binder	100	
Cementitious Compounds	%S x 2.5	6.4	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	2.3	
Soluble Silica in Original Binder	From %S x $\frac{(A + 1)}{B}$	3.2	
CaO in Original Binder	From CaO in mortar	55.7	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	40.3	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	-	
Cementation Index for Binder (CI)	CI $\approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	0.1	
Type of Binder	Dependent on the % Soluble Silica in Binder	Feebly hydraulic dolomitic lime (NHL1) + gypsum	

Methodology: A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques, in addition to polarised light microscopy, are used to determine the components and characteristics of the mortar sample, as shown in the results table.

Results of Plaster Analysis, Manchester Town Hall

Summary of Results and Comments:	The Aggregate: There is a very small proportion of aggregate in the sample tested, which is otherwise a fine grained buff, sharp buff colored silica sand. The Binder: is 1 part Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) 1.6 parts Moderately hydraulic, dolomitic lime. The Mortar: consists of 0.14 parts Aggregate : 1 part Gypsum : 1.6 parts Dolomitic lime.
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Appendix 9: IS.07.726.004 – Room 726, wall**Date Analysed:** 26/02/19**Sample:** Base Coat Wall Plaster on masonry/brick, IS.07.726.004 Manchester Town Hall**Observations:** A 13 - 15mm thick, reddish-brown-grey coloured, quite hard but readily crushed, fine - coarse grained mortar, with off-white inclusions of carbonated lime and very sparse hair.**RESULTS**

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO ₂ emission	6.5	
Dolomite %D	Calcimetry and titrimetric (EDTA)	1.7	
Aggregate	Gravimetric	84.6	
Gypsum	Barium Chloride	1.6	
Nitrates	Titrimetric/test strips.	0	
Chlorides	Titrimetric/test strips.	0	
Iron Oxides (Fe₂O₃)	Test strips/Titrimetric (potassium dichromate)	0.6	
pH of mortar sample	Indicator Strips/pH meter	7	
Mix Ratio if Gypsum was part Of the binder	Parts Aggregate	53.3	
	Parts Lime	4.1	
	Parts Gypsum	1	
Active lime [Ca(OH)₂]	Titrimetric (Extracted in 10% sugar solution)	0	
Carbonated lime in binder (degree of Carbonation)	From %Ca(OH) ₂ in binder	100	
Cementitious Compounds	%S x 2.5	5.0	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	1.8	
Soluble Silica in Original Binder	From %S x ($\frac{A}{B} + 1$)	15.7	
CaO in Original Binder	From CaO in mortar	53.2	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	6.0	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	-	
Cementation Index for Binder (CI)	CI $\approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	0.7	
Type of Binder	Dependent on the % Soluble Silica in Binder	Eminently hydraulic dolomitic lime (NHL5) + gypsum	

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	RETAINED MASS (gms)	% RETAINED	% PASSING	AGGREGATE CHARACTERISTICS
5.45		0	100	
2.465		2.57	97.42	Angular black-grey coke + iron oxides (magnetic) + red brick dust + off-white lithic fragments
0.915		2.57	94.85	As above
0.567		2.82	92.03	As above + angular clear/milky/yellow/rose quartz grains
0.411		3.34	88.68	As above
0.14		36.24	52.44	As above
0.09		26.73	25.70	As above
<0.09		25.70	0	As above

Methodology: A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques, in addition to polarised light microscopy, are used to determine the components and characteristics of the mortar sample, as shown in the results table.

Summary of Results and Comments:	The Aggregate: is a fine - coarse grained, grey-brown coloured essentially blast furnace iron slag material, which would have had a pozzolanic effect on the binder by virtue of its reaction with lime to produce calcium silicate cementitious compounds, giving added strength and set to the mortar:  Aggregate mag. x 10 The Binder: is 1 part Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) + 4.1 parts Moderately hydraulic, dolomitic lime. The Mortar: consists of 53.3 parts Aggregate : 1 part Gypsum : 4.1 parts Dolomitic lime.
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Date Analysed: 24/02/19**Sample:** Top Coat Wall Plaster on Masonry/brick, IS.07.726.004 Manchester Town Hall**Observations:** A 1 - 1.5mm thick, off-white coloured, fine grained, quite hard mortar.**RESULTS**

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO ₂ emission	29.3	
Dolomite %D	Calcimetry and titrimetric (EDTA)	3.0	
Aggregate	Gravimetric	62.2	
Gypsum	Barium Chloride	2	
Nitrates	Titrimetric/test strips.	0	
Chlorides	Titrimetric/test strips.	0	
Iron Oxides (Fe₂O₃)	Test strips/Titrimetric (K ₂ Cr ₂ O ₇)	0.3	
pH of mortar sample	Indicator Strips/pH meter	7	
Mix Ratio by Mass	Parts Aggregate : Parts Binder	1.7 : 1	
Mix Ratio by Volume (if binder was lime putty)	Parts Aggregate : Parts Binder	0.96 : 1	
Mix Ratio by Volume (if binder was Hydraulic lime or cement)	Parts Aggregate : Parts Binder	1.2 : 1	
Active lime [Ca(OH)₂]	Titrimetric (Extracted in 10% sugar solution)	0	
Carbonated lime in binder (degree of Carbonation)	From %Ca(OH) ₂ in binder	100	
Cementitious Compounds	%S x 2.5	3.3	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	1.2	
Soluble Silica in Original Binder	From: %S x $\frac{A+1}{B}$	4.1	
CaO in Original Binder	From CaO in mortar	64.7	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	18.4	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	-	
Cementation Index for Binder (CI)	$CI \approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	0.15	
Type of Binder or equivalent strength	Dependent on the % Soluble Silica in Binder	Feebly Hydraulic dolomitic lime (NHL2)	

A lime putty with 50% moisture by mass is considered in the calculations above. A greater percentage of moisture in the lime putty, gives a higher Aggregate : Binder ratio (by mass and/or volume)

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	RETAINED MASS (gms)	% RETAINED	% PASSING	AGGREGATE CHARACTERISTICS
5.45		0	100	
2.465		0	100	
0.915		0	100	
0.567		0.29	99.7	Angular black coke + iron oxides + red brick dust + off-white/grey lithic fragments + some quartz grains
0.411		0.17	99.52	As above but mostly angular clear/milky/yellow/rose quartz grains
0.14		55.15	44.36	As above
0.09		34.17	10.19	As above
<0.09		10.19	0	As above

Methodology: A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques, in addition to polarised light microscopy, are used to determine the components and characteristics of the mortar sample, as shown in the results table.

Summary of Results and Comments:	The Aggregate: is mostly a light warm buff coloured, fine grained sharp silica sand, with some grey/black coke and iron oxides (pozzolanic slag) + off-white/grey lithic fragments:
	 Aggregate mag. x 10 The Binder: is equivalent in strength to a moderately hydraulic, dolomitic lime. It was probably an on-site hot lime mix, which usually gives a characteristically low aggregate : binder mix ratio by volume. The small amount of slag material may have given the mortar a degree of hardness and set, by virtue of its reaction with the free lime content, producing cementitious calcium silicate compounds. The Mortar: has a mix ratio by volume of 0.96 – 1.2 : 1 aggregate : binder.

Appendix 10: IS.07.726.011 – Room 726**Date Analysed:** 23/02/19**Sample:** Base Coat Ceiling Plaster, IS.07.726.011 on wooden laths, Manchester Town Hall**Observations** A 20mm thick, firm, but readily crushed, fine – medium grained, grey coloured mortar, with sparse hair and inclusions of coal/charcoal.**RESULTS**

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO ₂ emission	7.9	
Dolomite %D	Calcimetry and titrimetric (EDTA)	4.5	
Aggregate	Gravimetric	82.3	
Gypsum	Barium Chloride	3	
Nitrates	Titrimetric/test strips.	0	
Chlorides	Titrimetric/test strips.	0	
Iron Oxides (Fe₂O₃)	Test strips/Titrimetric (potassium dichromate)	0.6	
pH of mortar sample	Indicator Strips/pH meter	7	
Mix Ratio if Gypsum was part Of the binder	Parts Aggregate	27.4	
	Parts Lime	2.6	
	Parts Gypsum	1	
Active lime [Ca(OH)₂]	Titrimetric (Extracted in 10% sugar solution)	0	
Carbonated lime in binder (degree of Carbonation)	From %Ca(OH) ₂ in binder	100	
Cementitious Compounds	%S x 2.5	1.8	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	0.64	
Soluble Silica in Original Binder	From %S x $\frac{(A + 1)}{B}$	4.8	
CaO in Original Binder	From CaO in mortar	47.1	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	6.2	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	-	
Cementation Index for Binder (CI)	$CI \approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	0.14	
Type of Binder	Dependent on the % Soluble Silica in Binder	Feebly Hydraulic dolomitic lime (NHL2) + gypsum	

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	RETAINED MASS (gms)	% RETAINED	% PASSING	AGGREGATE CHARACTERISTICS
5.45		0	100	
2.465		0	100	
0.915		6.72	93.27	Angular black coke + iron oxides + red-orange brick fragments + off-white lithic fragments
0.567		3.76	89.51	As above + sub angular clear/milky/yellow/rose quartz grains
0.411		5.91	83.60	As above but mostly sub angular clear/milky/yellow/rose quartz grains
0.14		45.69	37.90	As above
0.09		18.01	19.89	As above
<0.09		19.89	0	As above

Methodology: A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques, in addition to polarised light microscopy, are used to determine the components and characteristics of the mortar sample, as shown in the results table.

Summary of Results and Comments:	The Aggregate: is mostly a light warm buff coloured, fine grained sharp silica sand, with some grey/black coke and iron oxides (pozzolanic slag) + off-white/grey lithic fragments:  Aggregate mag. x 10 The Binder: is 1 part Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) + 2.6 parts Moderately hydraulic, dolomitic lime. The Mortar: consists of 27.4 parts Aggregate : 4 parts Gypsum : 1 part Dolomitic lime.
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Date Analysed: 21/02/19**Sample:** Top Coat Ceiling Plaster IS.07.726.011 Manchester Town Hall**Observations:** A 6 - 7mm thick, hard, off-white coloured, fine grained mortar.**RESULTS**

Components of Mortar	Method	Results % by mass	
Calcium Carbonate %C	Calcimetry - CO ₂ emission	23.1	
Dolomite %D	Calcimetry and titrimetric (EDTA)	detected	
Aggregate	Gravimetric	40.0	
Gypsum	Barium Chloride	31	
Nitrates	Titrimetric/test strips.	0	
Chlorides	Titrimetric/test strips.	0	
Iron Oxides (Fe ₂ O ₃)	Test strips/Titrimetric (potassium dichromate)	0.3	
pH of mortar sample	Indicator Strips/pH meter	7	
Mix Ratio if Gypsum was part Of the binder	Parts Aggregate	1.7	
	Parts Lime	1	
	Parts Gypsum	1.4	
Active lime [Ca(OH) ₂]	Titrimetric (Extracted in 10% sugar solution)	0	
Carbonated lime in binder (degree of Carbonation)	From %Ca(OH) ₂ in binder	100	
Cementitious Compounds	%S x 2.5	5.5	
Soluble Silica %S	Volumetric/Titrimetric - (Conversion to silicomolybdic acid)	2	
Soluble Silica in Original Binder	From %S x $\frac{(A + 1)}{B}$	4.4	
CaO in Original Binder	From CaO in mortar	61.1	
CaO in Mortar	Titrimetric (EDTA) Gravimetric (ammonium oxalate)	27.6	
Aluminium Oxide in Binder	Gravimetric (using Oxine)	-	
Cementation Index for Binder (CI)	CI $\approx \frac{\%S \times 2.5}{(\%C \times 0.56) + (\%D \times 1.5)}$	0.2	
Type of Binder	Dependent on the % Soluble Silica in Binder	Gypsum + hydraulic dolomitic lime	

ACID INSOLUBLES AGGREGATE MODE				
SIEVE SIZE	RETAINED MASS (gms)	% RETAINED	% PASSING	AGGREGATE CHARACTERISTICS
5.45		0	100	
2.465		0	100	
0.915		1.65	98.34	Angular coke/iron oxides + off-white lithic fragments + some quartz grains
0.567		6.61	91.73	As above
0.411		5.78	85.95	As above + angular/sub-rounded clear/milky/yellow/rose quartz grains
0.14		47.93	38.01	As above but mostly angular/sub-rounded clear/milky/yellow/rose quartz grains
0.09		24.79	13.22	As above
<0.09		13.22	0	As above

Methodology: A variety of specific volumetric, titrimetric, gravimetric and microchemical techniques, in addition to polarised light microscopy, are used to determine the components and characteristics of the mortar sample, as shown in the results table.

Summary of Results and Comments:	The Aggregate: is a mostly a light warm buff coloured, fine grained sharp silica sand, with some grey-black pozzolanic coke and iron oxides + off-white/grey lithic fragments:  Aggregate mag. x 10 The Binder: is 1.4 parts Gypsum (calcium sulphate hemi-hydrate, $\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$) 1 part Moderately hydraulic, dolomitic lime. The Mortar: consists of 1.7 parts Aggregate : 1.4 parts Gypsum : 1 part Dolomitic lime.
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