Measures to improve the resilience of historical buildings

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A new approach to problems

In recent years the effect of climate change has exacerbated the problems associated with our encroachment on flood zones, compounding the damage caused by each event.

The conventional approach is based on controlling the source of the flooding (river courses, tides, rainfall, etc.), reinforced by self-protection measures taken by the inhabitants and buildings affected. The need for action of this kind is most pressing in areas with large floodplains, where traditional measures (dams, channelisation, embankments) are inadequate or have excessively high environmental costs.

The Directorate General for Water (MITERD, Ministry for the Ecological Transition and the Demographic Challenge) set in motion a specially designed programme under a contract to conduct assessments and propose measures to improve resilience. This plan implies developing pilot programmes for adapting to flood risk and raising flood risk awareness in various economic sectors. Work was split three ways to assess the problems of three strategic sectors, i.e., agriculture, industry, and urban environments, the aspect dealt with in this article.

[1] MITERD: Ministerio para la Transición Ecológica y el Reto Demográfico (Ministry for the Ecological Transition and the Demographic Challenge).

Figure 1. Terrace of the Royal Mint building in Segovia under water during the 2014 flood.
Source: Radio Segovia.

Protecting river beds is a cornerstone of the EU's Water Framework Directive. Heavily dependent on that Directive is the 2007 Floods Directive, a component of the new approach that was transposed into Spanish law by Royal Decree 903/2010 [Real Decreto 903/2010].

The Dirección General del Agua [Directorate General for Water] (MITERD) [*Ministry for the Ecological Transition and the Demographic Challenge*] set in motion a specially designed programme under a contract to conduct assessments and propose measures to improve resilience, the "PLAN PIMA ADAPTA. DESARROLLO DE PROGRAMAS PILOTO DE ADAPTACIÓN AL RIESGO DE INUNDACIÓN Y DE FOMENTO DE LA CONSCIENCIA DEL RIESGO DE INUNDACIÓN EN DIVERSOS SECTORES ECONÓMICOS [*PIMA adaptation plan. Developing pilot programmes for adapting to flood risk and raising flood risk awareness in various economic sectors*]". Work was split three ways to assess the problems of three strategic sectors, i.e., agriculture, industry, and urban environments, the aspect dealt with in this article.

Accordingly, in areas where flooding occurs frequently, it is necessary to raise the awareness of the population so that people view self-protection during each extreme event as essential and take action over and above measures taken by the public authorities.

Self-protection encompasses both the buildings located in flood zones and the persons inhabiting them.

Protecting buildings: co-existing with floods

There are various procedures for mitigating or even completely preventing the damage floods can cause that can be followed for buildings located in a flood zone where flooding is frequent.

The process requires in-depth knowledge of both the levels the water can reach and the structure and functioning of the building considered.

There are four stages to the procedure:

- Ascertaining water levels in the building, based on both theoretical analyses (from studies made available by the SNCZI[2] and bespoke studies) and historical reports (information from building users and neighbours, an extremely important source).
- Diagnosing building condition, vulnerability of the structure and equipment, items of value inside, etc.
- Assessing and deciding on the strategy to be employed to protect the building and the most suitable measures that can be implemented.
- Designing the details of the solution selected and putting it into effect.

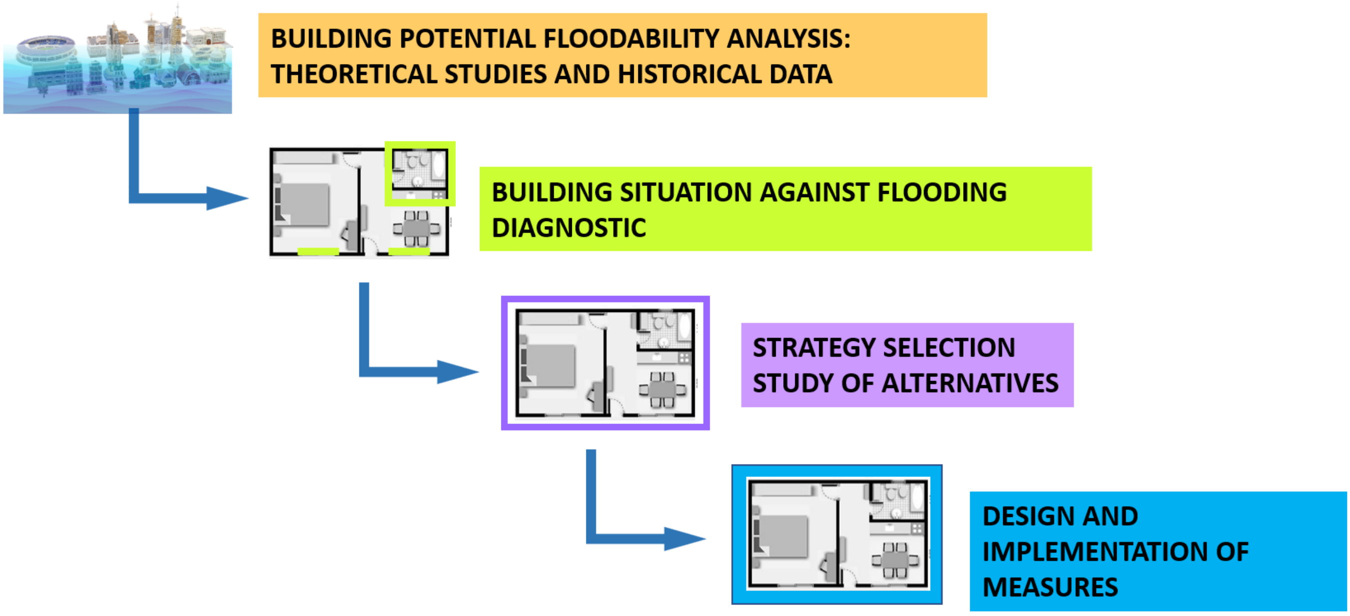

Figure 2. Procedure for selecting measures to be put in place.
Source: Created by the authors.

Diagnostics

Diagnosis involves ascertaining both the building elements (structure and contents) that might be damaged and vulnerabilities where water could gain entry to the inside.

[2] National Flood Zone Mapping Service (Spanish abbreviation: SNCZI).

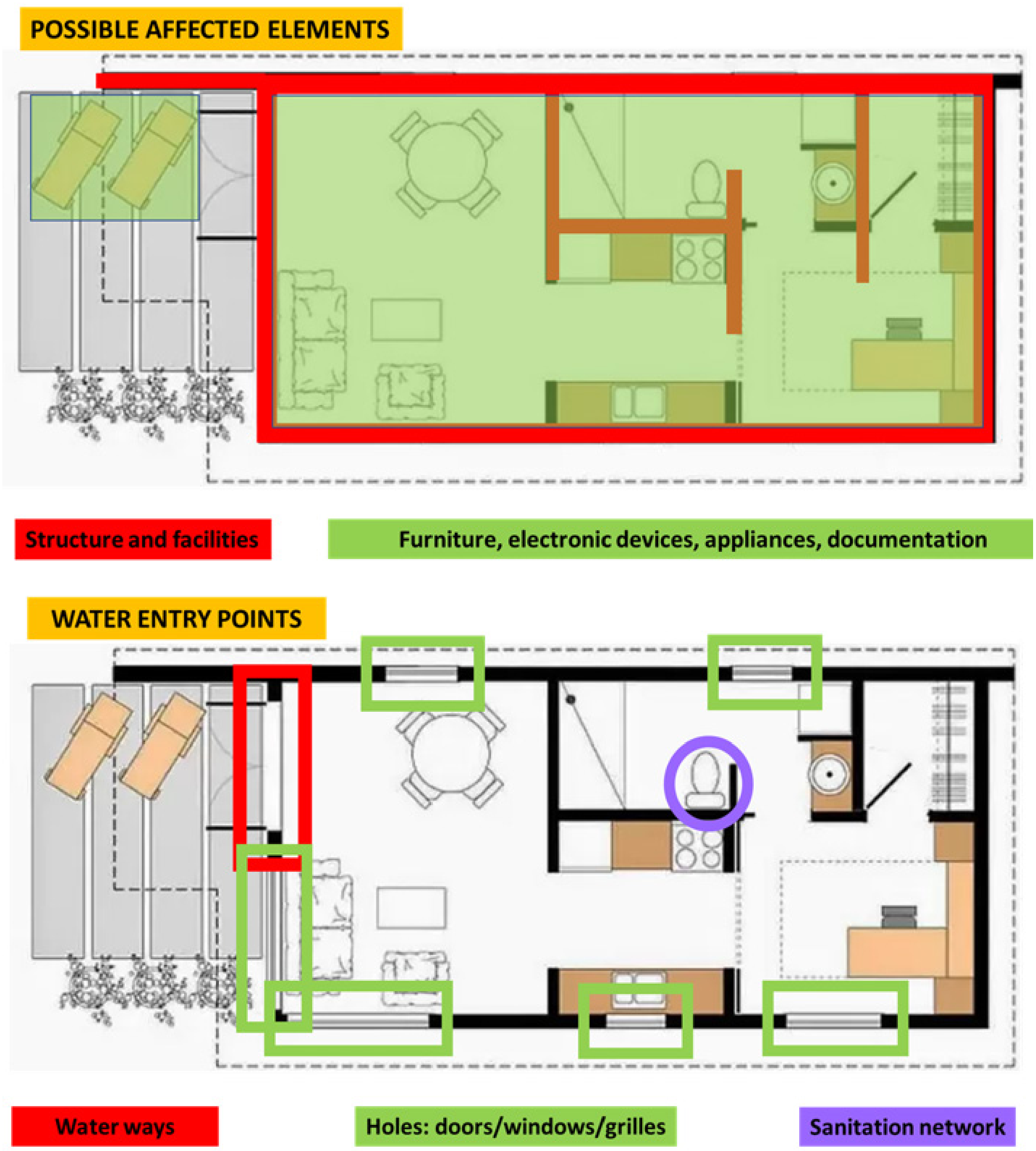

Figure 3. Building diagnostics.
Source: Created by the authors.

Strategies and measures

Potential measures that can be taken form a strategy that depends on the water-protection approach to be followed, that is, on how far water is to be kept away from the building.

There are four strategies:

- Avoidance: preventing water from coming near the building.
- Resistance: letting water reach the building but shielding the building to keep it from getting inside.
- Toleration: allowing water to enter the building while at the same time minimising vulnerabilities.
- Building removal (knocking down or moving the building).

Figure 4. Self-protection strategies.
Source: Created by the authors.

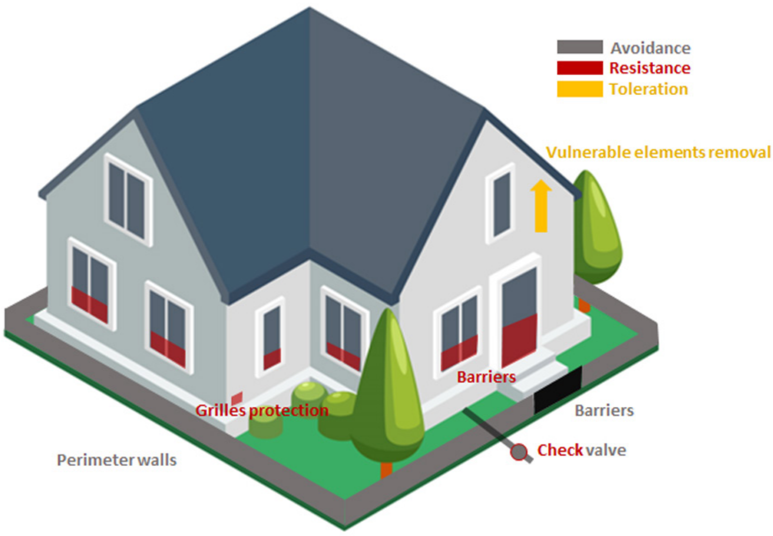

Figure 5. Typical self-protection strategy measures.
Source: Created by the authors.

The Ministry for the Ecological Transition and the Demographic Challenge has placed a series of easy-to-use technical guides that explain available risk reduction measures in depth at the disposal of the public on its website (in Spanish).

Figure 6. Available technical guides.
Source: MITERD.

Measures are wide ranging, but a brief consideration of the most usual measures follows based on the case studies presented, with a discussion of particular aspects attaching to historical buildings.

The predominant **AVOIDANCE** strategy measures include building walls and erecting temporary aluminium-panel barriers and flood grating (light plastic-coated panels installed on the fly). Inflatable or modular barriers work very well for low budgets where flood water depth is low. Premium solutions include floodgates that rise automatically in response to by water pressure, but they are high-cost solutions that are only justifiable where damage is likely to be considerable, and they can be difficult to integrate into cultural heritage buildings.

Figure 7. Most common AVOIDANCE strategy measures.
Source: Various sources.

Predominant **RESISTANCE** strategy measures include waterproofing exterior walls against exposure to water, using temporary floodgate panel-type barriers to raise the thresholds of doors and windows, installing watertight doors and windows or check valves at pipe connection points to prevent water from entering through overflowing water supply and drainage systems, and temporarily sealing ventilation grilles. Measures involving permanent watertight doors and windows can be difficult to integrate into historical buildings.

Figure 8. Most common RESISTANCE strategy measures.
Source: Various sources.

Predominant **TOLERATION** strategy measures include installing water-resistant materials, moving or individually protecting important equipment and items, and installing dewatering pumping systems at ground or basement level.

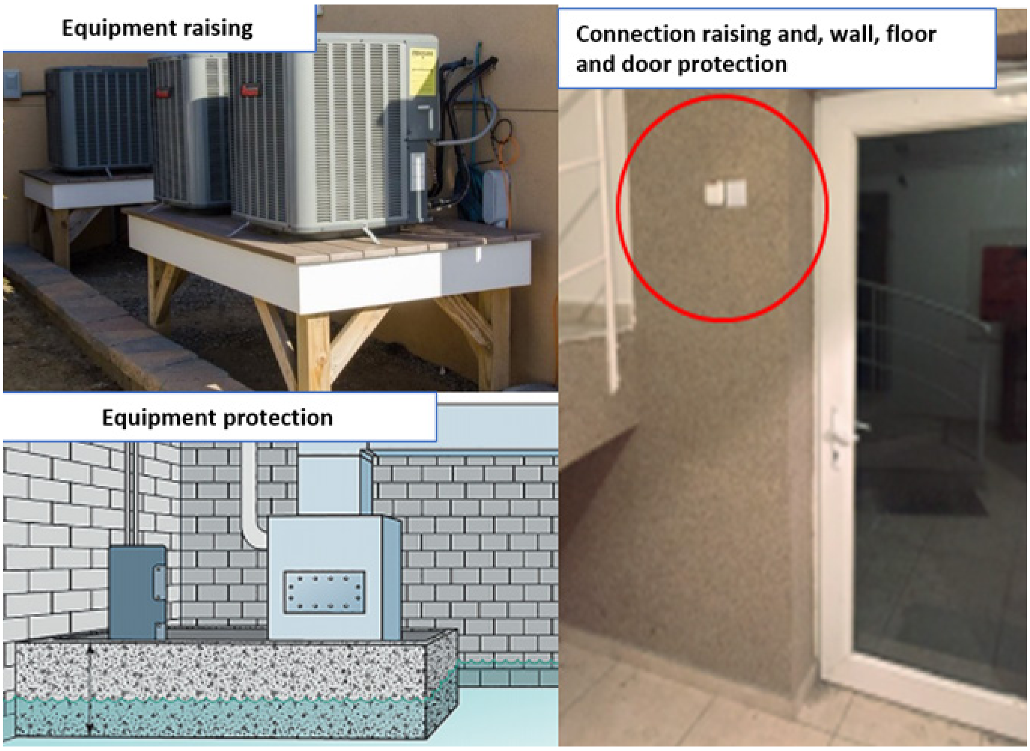

Figure 9. Most common TOLERATION strategy measures.
Source: Various sources.

The **REMOVAL** strategy entails moving facilities out of the flood zone and normally requires a far-reaching social consensus. It does not fall within the scope of available options for cultural heritage sites.

Case in point: The Royal Mint building in Segovia

A mint was built in Segovia (Castile and Leon, Spain; at about 90 km NW of Madrid) on orders from King Philip II in the late sixteenth century. It was located close by the Eresma River to be able to put the river's flow to use as a source of power. This Herrerian style[3] building was built to be used as a mint for coinage. Later it was converted into a flour mill, and later still it was abandoned until the Royal Segovia Mint Museum was established.

Historically, flooding has persisted up until the present day (2009, 2013, 2014, 2016, 2019, and 2020), notwithstanding the Pontón Alto dam that was built in the upper Eresma River basin upstream from the Mint in 1995-1996. The dam is primarily intended for water supply purposes, but it has some ability to regulate and smooth out the freshets that recur with short return periods. The Mint is located outside the city's walls, upstream of the San Marcos district, as can be seen in the following orthoimage.

[3] Late Renaissance Spanish style, named after the Spanish architect Juan de Herrera, characterized by its austerity and minimalism.

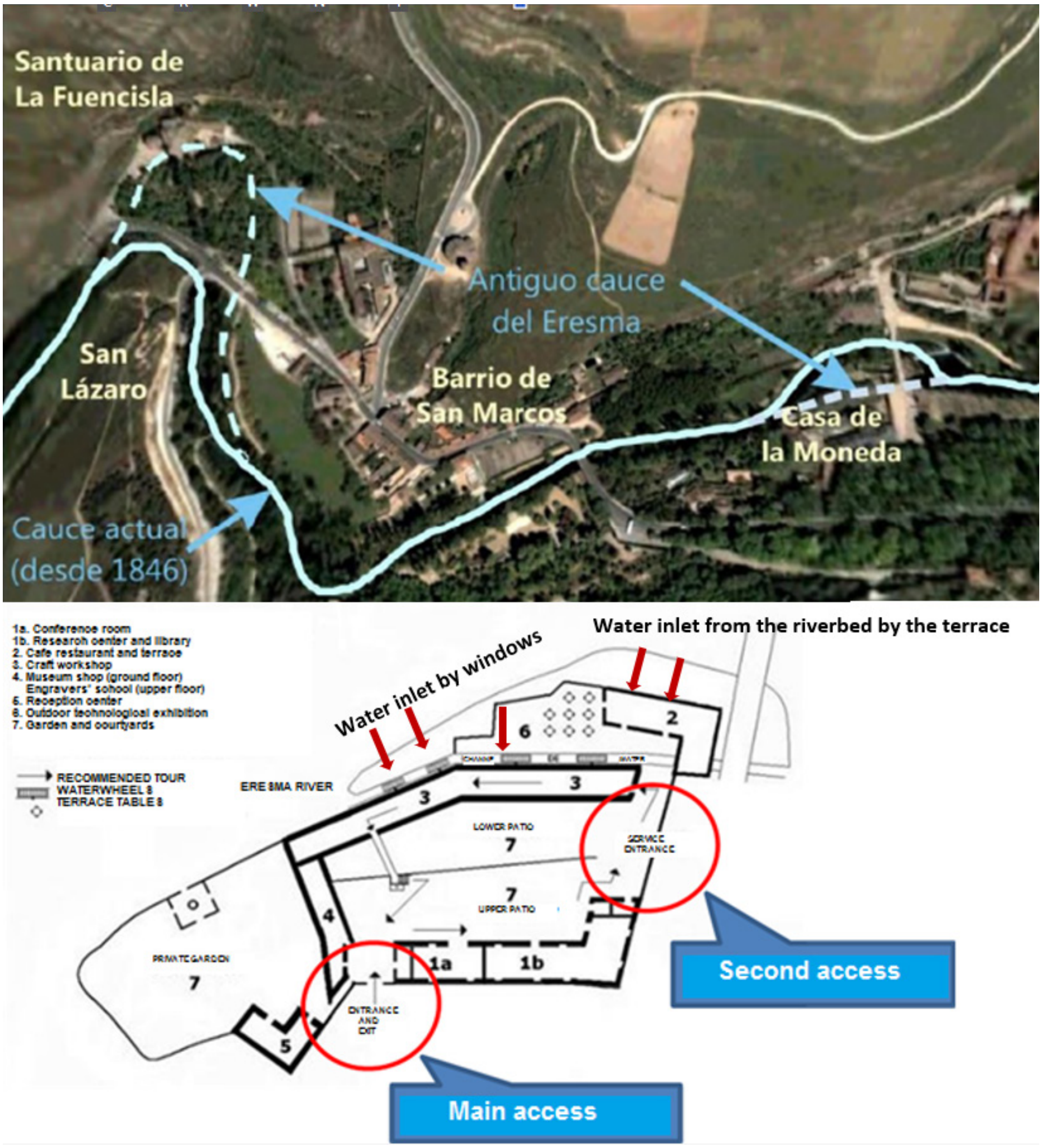

Figure 10. Site of the Royal Segovia Mint.
Source: Google Maps and the Segovia City Council.

The Royal Segovia Mint has, then, experienced episodes of flooding right from the start because of its highly exposed location in the paleo basin along the original channel of the Eresma River. That exposure has been intensified by the narrowing produced by construction of the terrace and safety barrier for the El Ingenio Chico cafeteria and more recently by construction of a gabion wall that decreases the size of the floodplain along the bank opposite the Mint (right-hand margin).

After the 2013 and 2014 floods, the Mint's management undertook a series of measures intended to provide protection:

- The wall between the workshop and the channel was waterproofed.
- Safety glass in metal frames was installed in the windows in the area where the workshop is located along with extra protection in the form of reinforcement with wooden boards to ensure that the windows can withstand the pushing of the waters and stay shut.
- The inside of the drainage system was revamped.
- A 60 cm-high parapet was built on top of the brick wall surrounding the terrace of the El Ingenio Chico cafeteria, made of safety glass attached to the wall by a system of metal fasteners.
- Two floodgates were installed to regulate the river water entering the channels during episodes of high water, along with metal grates in front of the channels to prevent solid objects from blocking the floodgates and keeping them from working properly. A pump and other smaller components were installed as further protection against freshets.

Figure 11. Cafeteria terrace bordering on the river channel.
Source: MITERD.

Some of these measures are in line with the proposals made below, but others, like the glass parapet along the terrace wall, can sometimes make the problem worse. In any event, they were not able to stop the damage from being repeated in 2020.

Figure 12. Flooding of the lower patio and the water level mark after the 2020 event.
Source: The Royal Mint.

In the circumstances, it was decided to undertake a case study in the framework of the contract mentioned to in section 1 above. The facility was inspected twice, the corresponding diagnosis was made, and a series of measures were put forward combining two of the strategies recommended in the guides:

- The **RESISTANCE** measures proposed were to allow the water to flow along the terrace outside the El Ingenio Chico cafeteria, waterproof the walls, replace the window panes, and install temporary barriers in the openings. Installing check valves in the water supply and drainage system was also recommended.

- The **TOLERATION** measures proposed were to raise the entire electrical system and the communications system rack and to replace the existing dewatering pumps with more powerful pumps.

Additional AVOIDANCE interventions were assessed and proposed in the initial draft of the study to improve the behaviour of water flow in the adjacent stretch of the Eresma River to reduce flooding depth in the vicinity of the Mint and thus enhance the performance of the other planned measures.

REMOVAL is not considered an option given the high historical value of this heritage building.

The final proposal thus included the following package of measures:

- **Water should be allowed to flow into the terrace of the El Ingenio Chico cafeteria** at a specified water height. At present the terrace wall has been raised by attaching transparent panels.

  This is to be done by removing the glass parapet and replacing it with a steel railing or balustrade that will allow water to pass through. Another proposal is to simultaneously make small (0.25 x 0.5 m) openings in the wall at 2-m intervals to allow waters to spread out in that section and thus keep the river from reaching even higher depths in the area surrounding the Mint.

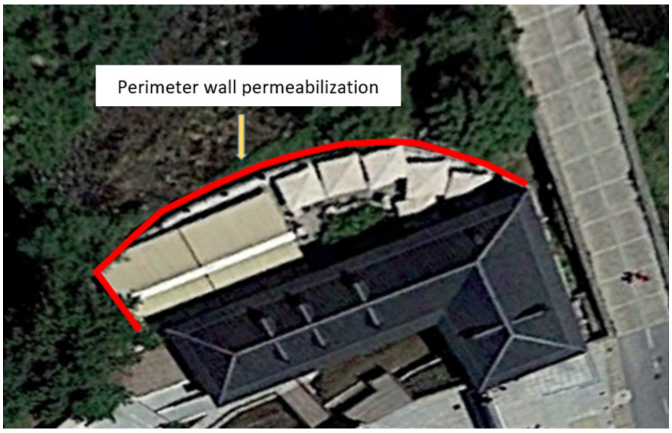

Figure 13. Measures in the terrace wall of the El Ingenio Chico cafeteria.
Source: Google Maps.

Figure 14. Measures in the wall bordering the terrace of the El Ingenio Chico cafeteria.
Source: MITERD.

Since it allows water to pass onto the cafeteria terrace, this measure makes necessary other measures designed to protect the part of the building exposed to the waters. There are various options, the best one being to install redundant systems for back-up protection of the facility, especially if certain depth thresholds are exceeded.

- Protecting the building's walls along the terrace of the El Ingenio Chico cafeteria up to a height of 1.5 m.
- Replacing the glazing in the windows and door opening onto the cafeteria terrace with new safety glass panes (10+10) capable of withstanding the pressure of the water.

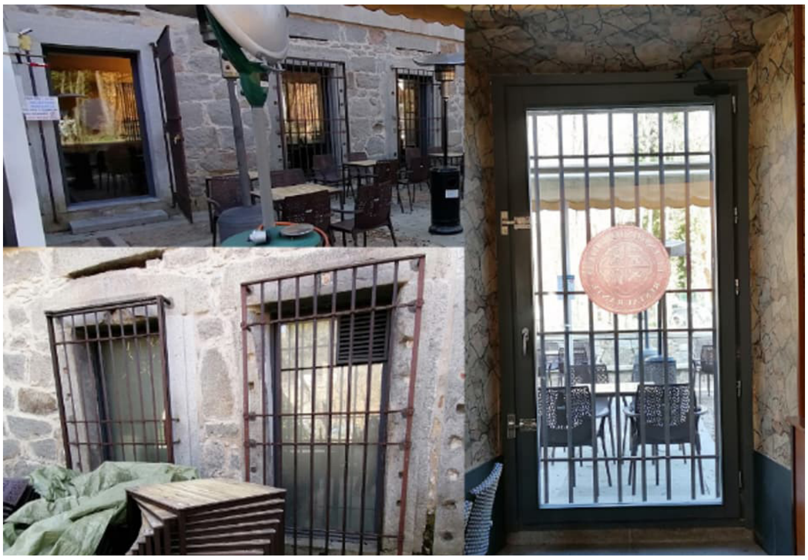

Figure 15. Doors and windows opening onto the terrace of the El Ingenio Chico cafeteria that need to be strengthened.
Source: MITERD.

- Installing temporary barriers at least 1.5 m in height in the doors and windows opening onto the cafeteria terrace as a back-up system to the (10+10) safety glass installed.
- Waterproofing the wall between the workshop and the channel with Bentofix, a controlled swelling material made of bentonite clay waterproofing geocomposites.
- Installing 10+10 glazing in the workshop windows opening onto the Eresma River and a back-up system of temporary (slim-line) flood barriers 1.2 m high from the window sill, to limit, or even prevent, the damage these rooms and the museum have suffered in past floods.

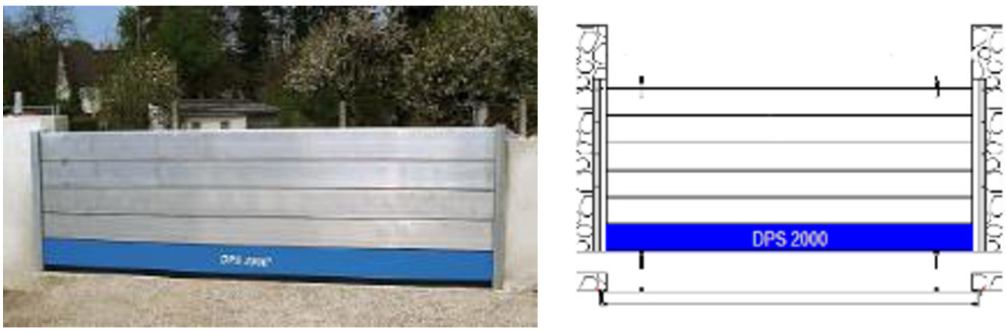

Figure 16. Modular floodgates for the main entrance doorway to the El Ingenio Chico cafeteria.
Source: CAG Canalizaciones S.L. catalogue.

- Installing an O-ring seal to prevent water from gaining entry through machinery shaft apertures.
- Waterproofing the lift pit and drainage system.
- Installing check valves at the pipe connection points for the water supply and drainage system and sealing the pipe grommets in the sump chambers.

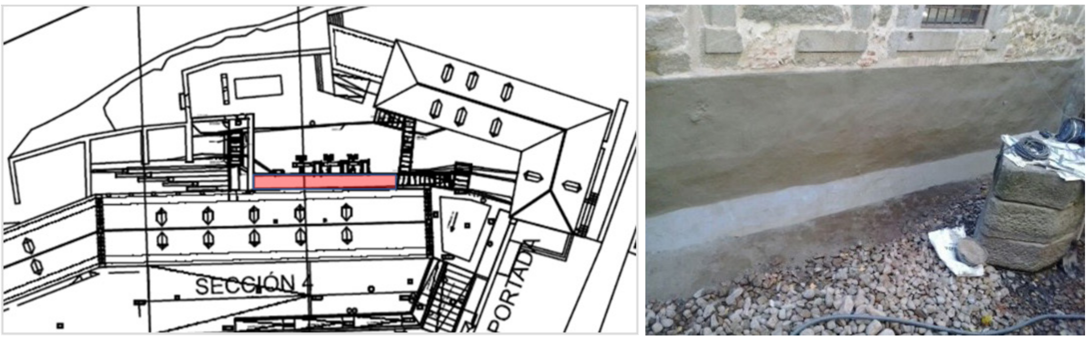

Figure 17. Floor plan showing the location of the channel to be waterproofed and a detail of the channel.
Source: The Royal Mint.

- Raising the entire electrical system and the communications system rack from their current location to above the flood level.

Figure 18. Detail of the existing reinforcement system for workshop windows.
Source: The Royal Mint.

- Installing two additional pumps to increasing the dewatering capacity of the drainage sump and enlarging the existing storm tank in the inner courtyard from 3x3x3 m to 9x6x3 m.

Figure 19. Museum machinery shafts.
Source: MITERD.

The cost of these measures comes to around 165,000 euros, compared with the estimated costs of the damage in 2020, including the time the museum was closed, totalling 192,384 euros.

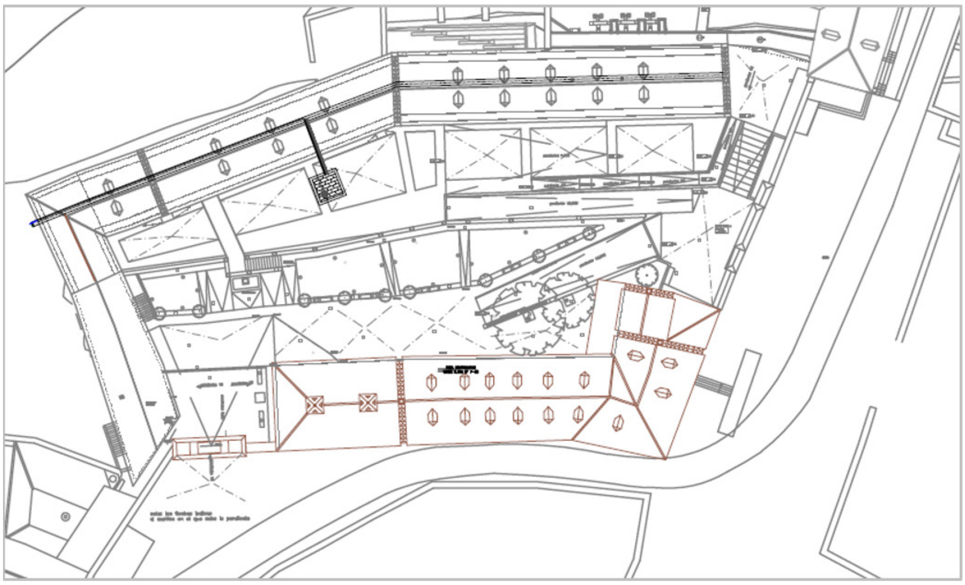

Figure 20. Floor plan of the location of the existing storm tank.
Source: The Royal Mint.

Lastly, notwithstanding these measures designed to keep the building itself safe, as a further safety measure the venue will need to be evacuated during floods, and the building management should follow the following general recommendations:

1. Keep a list of emergency telephones and register with flood alert services: Civil Defence Corps, National Weather Service (Spanish abbreviation: AEMET), the Duero basin Water Management Authority's Automatic Reporting System (Spanish abbreviation: SAIH), the mass media, social media and apps.
2. Purchase property damage, business interruption and vehicle insurance.
3. Implement a self-protection plan and practice evacuations.
4. Become familiar with the Regional Government of Castile and Leon's Flood Risk Civil Defence Plan [*Plan de protección civil ante el riesgo de inundaciones en la Comunidad de Castilla y León (INUNcyl)*] and the Segovia City Council's Flood and High Water Risk Safety Guide [*Precauciones ante el riesgo de avenidas e inundaciones de Protección Civil del Ayuntamiento de Segovia*].

Figure 21. Civil Defence self-protection guides.

Conclusions

Adapting cultural heritage assets to be able to withstand flood risks must be a priority objective in view of their high intangible value. While the general measures set out in technical building and safety guides remain worthwhile, REMOVAL is not an option, and installing certain RESISTANCE strategy measures in historical buildings may not be readily feasible.

Partly because of the difficulties encountered in implementing measures of this kind, the cost-benefit ratio for these renovation measures is not as good as for other types of buildings and needs to be buttressed with new quantitative and qualitative indicators that include assessing the indirect benefits obtaining from renovation work, especially where these measures bring new social, economic, and environmental advantages.