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A GUIDE FOR MONITORING THE EFFECTS OF CLIMATE CHANGE ON HERITAGE BUILDING MATERIALS AND ELEMENTS

Report prepared for the funded research project:

‘Heritage Building Information Modelling and Smart Heritage Buildings
Performance Measurements for Sustainability’

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1. Heritage Definition

1.1. Heritage Value

Since the beginning of humanity as we know it, and across different space and time, people have always lived lives dominated by contradicting values; a conflict between the classical romance, and that of realism and materialism. Nonetheless, it is a fact that the power of the material world has always prevailed as the controlling factor in the fate of human beings. From this retrospect, civilizations have flourished and disappeared, yet what remains of them is a legacy of the values on which they were based. Accordingly, heritage values of all kinds have a cultural significance that emphasizes the importance and feasibility of preserving its elements, and the legacy of its ancestors to prevent their extinction and keep their beliefs alive through many generations to come. Heritage values can be categorized as follows:

- **Historical Values:** Expresses a traditional meaning, among them historical temporal relevance and historical symbolic ones.
- **Aesthetic Values:** Reflects human interactions towards unique creative abilities.
- **Functional Values:** Expressing social and economic patterns.

However, the danger occurs from the fact that society inherits a value that is not seen or realized by it, the same way that monetary values are, and is hidden in the corners of oblivion until it forever disappears: the emotional value. Without that sentimental value amid our conscious minds, our responsibility towards the inherited entity could fail us and our descendants by our own greed or excessive practicality, through reaching a wrong decision towards how to deal with it. Therefore, it is necessary to consciously recognize the values in inherited buildings, elements and others first, in order to determine the usefulness and importance of conservation or the continuation of its life.

From this point of view, heritage everywhere needs those who appreciate its full value, care for it, and maintain its continuity in the life of societies. Taking into consideration that it is not necessary that anything old contains a heritage value, unless the community perceives it as such, and appreciates the usefulness and importance of what the predecessor has left, because it is only then that it could be considered the heritage of society.

1.2. What is a Heritage Building?

The memory of human beings is the strength of their existence; the identity and personality of which the individual otherwise loses their uniqueness and distinctiveness from other creatures. Similarly, the memory of the cities is their old buildings and historical districts; consequently, preserving them and prolonging their vibrant lives means keeping their memories strong and refreshed, and as a result, conserving their heritage and their civilization as a renaissance to coming generations.

Thus, heritage buildings play an essential role in confirming the identity of cities and enriching their cultural heritage.

A heritage building is not only considered a monument that passed 100 years, but it is also a building that expresses a sense of cultural, historical, social, architectural, urban and symbolic value. It is a property that may be inherited, or passed down from previous generations to deliver a full range of culture, meanings, traditions and objects of values that are worthy of preservation.

Heritage buildings are usually defined as living or non-living (frozen) heritage according to their usefulness, because some heritage buildings still retain their functional value, while others have gradually lost their usefulness and have become unused or have been used for other purposes that do not match the purpose for which they were created.

Generally, heritage buildings, monuments, objects, and places need to be formally protected by local and international heritage laws, regulations, and charters.

1.3. Heritage Buildings in Egypt

According to Egyptian laws for heritage saving, a heritage building is defined as follows:

First one is law number 117/1983 for “Monuments Protection”, which has been modified in 2010, a building or any artifacts produced by different cultures since the prehistoric era till a 100 years ago, when it held value or had archaeological or historic importance is considered one of the manifestations of different cultures.

Second one is law number 144/2006 on: “The regulation of demolition of unthreatened buildings and structures and the conservation of the architectural heritage”, a building is considered as heritage building but not a monument if it meets one or more of these criteria:

- a. A building of outstanding architectural style
- b. That is associated with the national history
- c. That is linked with a famous or historical figure
- d. That represent a historic era
- e. That is considered a tourist attraction
- f. A building of architectural/urban importance

1.4. Examples of Heritage Buildings in Egypt



Figure 1 Abdeen palace 1872 Cairo, considered as heritage building, it meets the criteria: Neo-Classic style, associated with the national history and the famous ruler of Egypt “Khedive Ismail”



Figure 2 Cairo University, early 20th century Giza, Egypt, considered as heritage building, it meets the criteria :Baroque & Neo-Classic style, associated with the national history and represents a historic era.



Figure 3 Cairo Tower 1956, Zamalek Cairo, designed by “Naoum Shebib” and associated with the national history



Figure 4 Cinema Radio, early 20th century, Khedivian Cairo Talaat Harb street, considered a building of “Art Deco” architectural

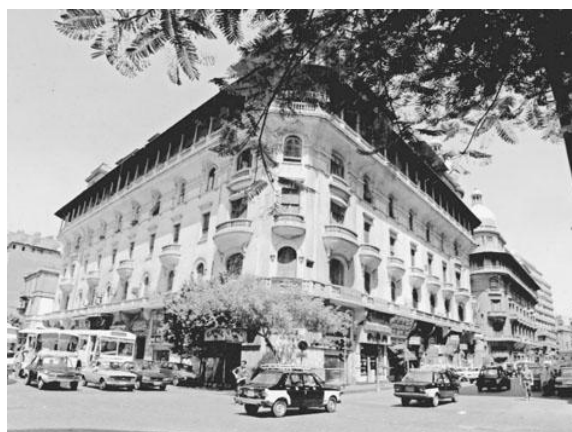


Figure 5 Old image for "Khedivial Building", 1911, Emad El-Din street, designed by "Antonio Lasciac", considered a building of "Neo-Baroque" architectural style



Figure 6 Old image for the department store "Taring", 1928, Ataba square, designed by "Oscar Horowitz", considered a building of "Neo-Baroque" architectural style

1.5. Heritage Building Registration in Egypt

1.5.1. Registration Levels

Three registration levels are considered in listing heritage buildings which are:

Level A: Identification of a heritage building according to this level means it is conserved on high standard, and no changes are allowed from outside (facades) and inside.

Level B: Identification of a heritage building according to this level means it is conserved on high standard, and no changes are allowed from outside (facades) with a degree of flexibility in decisions for changes inside the building. This is usually applied in residential buildings to enable the occupants to adopt with necessary facilities.

Level C: Identification of a heritage building according to this level means it is conserved on high standard without changes outside (facades) the building within complete allowance inside the building up to the demolition, applying the 'Facadism' approach. According to this control method the image of the city, district and street keeps its memory and features.

1.5.2. Registration Mechanism

A formed committee or more in each governorate is responsible to survey buildings and structures referred to the criteria mentioned above and to revise this survey on a regular basis. The concerned Governor shall elevate the committee's decisions to the Prime Minister, who issues a decree for the identification of heritage buildings and structures therefore they become listed, protected and conserved.

The "form" for "Valuable building registration" used by the committee as a tool to be filled during their survey is shown in (fig. 7). This form includes all information available about a heritage building, but not any of environmental information which could affect the building condition and help by taking technical decisions to maintain or to preserve the building.

The data included in the "Valuable Building Registration Form" is still insufficient for many cases of a heritage building restoration because it is still not covering all data of importance such as the architect's name, details of any previous restoration, number of families living in the building who will need to be housed during critical cases in restoration projects, also number of shops in ground floor and the legal status of the building.

Architectural drawings like plans, sections and ornaments details are also not included, which makes any restoration projects more difficult and incomplete. This explains the reason for great interest in "heritage building information modeling", H-BIM to be applied as an inevitable tool in saving more than 3000 heritage buildings in Cairo.

Cairo Governarate

محافظة القاهرة
سجل المباني والمنشآت ذات الطراز المعماري المتميز

رقم التوثيق 5

المنطقة 1 الفريدة 2 حى 3

تاريخ المعاينة والتصوير 3 مستوى التصنيف والحماية 4

العنوان 6

نوع المبنى 7 الاستخدام الحالي 8

المالك 9

عدد الأدوار 10 مساحة الدور الأرضي 11

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خريطة مساحية لموقع المبنى 31

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Figure 7 Valuable Building Registration Form

- Registratio Form Content
- 1. Zone
- 2. District
- 3. Date of survey and imaging
- 4. Registration level
- 5. Authentication number
- 6. Property Address
- 7. Type of building (a. Palace b. Villa c. Building d. Other ...)
- 8. Current use (a. Residential b. c. commercial d. commercial/ administrative e. residential/commercial f. residential/commercial/ administrative g. religious h. health i. cultural n. recreational ... others)
- 9. Owner
- 10. Number of floors
- 11. Ground floor area
- 12. Date of construction
- 13. Structural condition (a. good b. stable c. bad)
- 14. Structural system (a. Bearing walls b. Concrete structure ... others)
- 15. Architectural style
- 16. Garden (a. existing b. not existing)
- 17. Recent modifications (a. Yes b. No)
- 18. Additions (a. Yes b. No)
- 19. Occupants (Inhabited - Uninhabited)
- 20. Intervention status (a. urgent b. not urgent c. no need)
- 21. Number of flats/building
- 22. Number of flats/floor
- 23. Facilities
- 24. Connected to: a. the sewer system
- 25. Connected to the water network
- 26. Connected to the power grid

27. Value of property (a. outstanding architectural style b. associated with the national history c. linked with a famous or historical figure d. represent a historic era e. considered a tourist attraction f. architectural and urban importance)
28. Located in a significant listed area
29. The opinion
30. Notes and recommendations
31. Old pictures for the building if available
32. Recent pictures for the building (a. main facades b. side facades)
33. Property location on a map
34. Chair and Committee members (to be signed)

2. Climate Change

2.1. What is Climate Change?

Buildings can be vulnerable to climate change, especially heritage buildings. However in order to understand the relationship between buildings and climate change, one must first completely comprehend what climate change indicates. Climate change is defined as a change in global or regional climate patterns, in particular a change apparent from the mid to late 20th century onwards and attributed largely to the increased level of atmospheric carbon dioxide produced by the use of fossil fuels. According to an article published by NASA, climate change is a change in the typical or average weather of a region or city. This could be a change in a region's average annual rainfall, for example. Or it could be a change in a city's average temperature for a given month or season. Moreover, climate change was also defined as a change in Earth's overall climate. This could be a change in Earth's average temperature, for example. It could also be a change in Earth's typical precipitation patterns.

Climate Change is not a recent phenomenon, earth's climate is always changing. In the past, it has gone through warmer and cooler periods each lasting thousands of years. However, for the past decade observations have shown that earth's climate has been warming.

The Earth's climate has changed throughout history. Just in the last 650,000 years there have been seven cycles of glacial advance and retreat, with the abrupt end of the last ice age about 7,000 years ago marking the beginning of the modern climate era — and of human civilization. Most of these climate changes are attributed to very small variations in Earth's orbit that change the amount of solar energy our planet receives.

The evidence of rapid climate change is compelling. The most apparent and directly affective phenomenon is Global Temperature Rise or Global Warming. The current warming tendency is very alerting because according to the IPCC Fifth Assessment Report, most of it is extremely likely (greater than 95% probability) to be the result of human activity since the mid-20th century and proceeding at a rate that is unprecedented over decades to millennia (IPCC, Fifth Assessment Report: Climate Change 2014 Synthesis Report Summary for Policy Makers, 2014). The heat-trapping nature of carbon dioxide

and other gases was demonstrated in the mid-19th century as the main cause of the global warming phenomenon.

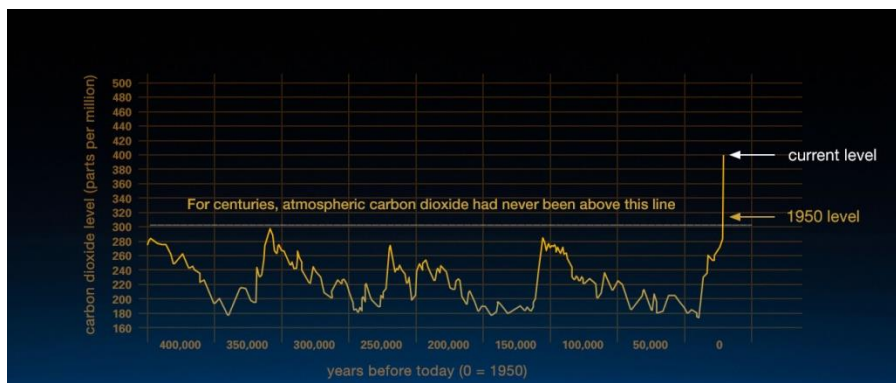


Figure 8 CO2 Levels, NASA, 2017

Since the late 19th century, the average temperature of the planet has risen about 2.00 degrees Fahrenheit (1.1 degrees Celsius) (NASA, 2017) (CRU, 2016) (NOAA, 2017). This change is largely driven by increased carbon dioxide and other human-made emissions into the atmosphere. The most obvious warming patterns were in the past 35 years with 16 of the 17 warmest years on record since 2001. Not only was 2016 the warmest year on record, but eight of the 12 months that make up the year — from January through September, with the exception of June — were the warmest on record for those respective months (NASA, 2017).

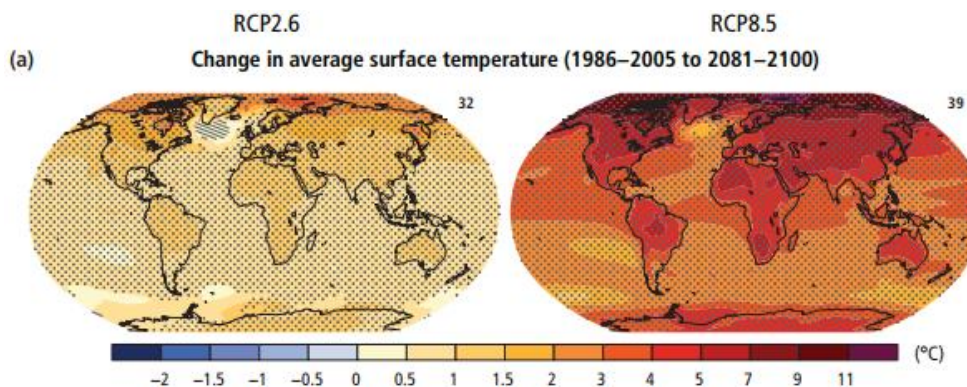


Figure 9 Changes in average surface temperature, IPCC, 2014

2.2. Global to Regional Climate Change

Climate change is now well evidenced and understood, the changes to the global climate and its and mankind’s input to this change are documented. Climate change is often thought of as “global warming” but the consequences are far more wide ranging. The IPCC (Intergovernmental Panel on Climate Change) make predictions regarding series of climatic changes on a global level by the early 21st and late 21st century (Qin et al. 2013), they can be seen in Table 1.

Table 1 - Likelihood of climate change events in the early and late 21st century. (Qin et al. 2013)

Climatic changes and trend	Likelihood of global scale change in early 21 st century (2016-2035)	Likelihood of global scale change in late 21st century (2081-2100)
Warmer and/or fewer cold days and nights over most land areas	Likely	Virtually certain
Warmer and/or more frequent hot days and nights over most land areas	Likely	Virtually certain
Warm spells/heat waves. Frequency and/or duration increases over most land areas	Unknown	Very likely
Heavy precipitation events. Increase in the frequency, intensity, and/or amount of heavy precipitation	Likely over many land areas	Very likely
Increases in intensity and/or duration of drought	Low confidence	Likely on a regional to global scale
Increases in intense tropical cyclone activity	Low confidence	More likely than not
Increased incidence and/or magnitude of extreme high sea level	Likely	Very likely

As illustrated in Table 1 the predicted changes in climate are not simply changes to temperature. Other climatic features such as rising sea levels, increases in cyclone activity and precipitation levels are all predicted for the late 21st century.

These predicted changes to climates have been found to have a significant effect on the fabric of heritage buildings across the globe (Sabbioni et al. 2010). The effects on buildings are wide ranging and vary from continent to continent. What follows is an overview of the effects known, and how they can be monitored. This will be specific to the HBIM project, using only techniques and measurements deployed in this project.

Although climate change is a global phenomenon, variations in the weather often have a regional impact. Particular variations can have greater influence over a locale than others, where subsequent effects due to a change in climate can manifest.

On a large scale, climate change has been observed to have interhemispheric disproportionality. Friedman et al. (2013), reviewed historic data collected between 1880 and 1999 and, using weather prediction models, forecast anomalies in surface air temperatures for each hemisphere. Their models revealed greater anomaly in the projected temperatures for the northern hemisphere than the southern. It is speculated that this disparity is due to an imbalance of greenhouse gas emissions across each hemisphere.

A similar investigation was carried out by Feulner et al. (2013), who delineated the contributory factors of surface air temperature distribution pre-industrialisation. They trace this general distribution and an initial interhemispherical temperature disproportionality to oceanic heat transport and varying polar influences. Since industrialisation however, Feulner et al. determined that high greenhouse gas emissions impact on several global factors, contributing to an evolution of the contrast between the temperatures within each hemisphere. They conclude that the Northern hemisphere is 1o-2oC warmer on average than the Southern hemisphere.

The study by Feulner et al. also divided each hemisphere to represent variation of the surface air temperature as a function of latitude. Given the initial disparity in temperatures, it is evident that a globally changing climate will impact differently – surface air temperature in particular – with much more regional dependency than just interhemispheric disproportionality.

It should be noted that unless stated, the SRES A1B emissions scenario has been used in generating discussed climate change forecasts. The SRES A1B scenario (IPCC, 2000) is identified out of a number of possible future emissions scenarios as having: rapid economic and population growth, rapid adaptation to efficient technologies, and a balanced dependency across all fuel sources.

Reducing the regional climatic range to the continental level offers greater complexity of the current climate and the forecast change in that climate. Boko et al. (2007) review the variation in climate change across Africa for example, identifying inconsistencies in the weather patterns across the continent. Annual temperatures increase for tropical regions of Africa were measured at 0.03oC/year, whereas in the South of Africa, the annual increase fell anywhere between 0.01oC/year and 0.03oC/year (Malhi and Wright, 2004; Kruger and Shongwe, 2004). Rainfall demonstrated similar regional variation, with historical data showing disproportional change in annual precipitation for Western regions of Africa when compared to the tropical regions of Africa. Western regions for example experienced an average decrease in rainfall of 30% between 1968-1990 (Chappell and Agnew, 2004; Dai et al., 2004); during a similar time period, the annual rainfall at tropical regions of Africa fell by an average of just 3% (Malhi and Wright, 2004).

Similar disparity of weather disparity and asymmetry of climate change impact exists across Europe. The EEA report on climate change and its impacts across Europe (Füssel and Jol, 2012). The average rise in surface air temperature for the continent was found to be 0.13oC/year (when using historical climate data between 1850 and 2011); greater seasonal contrast was also found, indicating summers are becoming warmer in particular. Work by van der Linden and Mitchell (2009) generated projections on how this warming might change between 2020 and 2100. They predict that surface air temperatures over Europe will rise higher than that found for the average global surface air temperature – with an increase of up to 4oC by 2100.

Further to this, the EEA report distinguishes certain regions across Europe that demonstrate variance of increasing temperatures. Impact of climate change on these regions can be identified not only spatially but temporally – observing different effects seasonally. Greater warming is anticipated during the summer for Southern European locales, whereas in winter there is a proclivity towards warming in the North Eastern portion of Europe.

Haylock et al. (2008) collate data from a vast array of weather stations across mainland Europe to investigate the historical variation in precipitation between 1950 and 2006. Analysis of their data showed that no significant change had occurred throughout this period, however a distinct asymmetry across the continent did exist for the impact of climate change on precipitation as it does for temperature. Past data for two separate locations – Spain and Portugal in Southern Europe, and Norway and Sweden in Northern Europe – are studied to reveal trends in precipitation as the climate changes throughout the test period. Impact of climate change is distinctly different for both locales; the Southern European location demonstrated an average annual decrease in precipitation of 3.0mm/year, whereas the Northern European location had an average annual increase of 3.6mm/year. Haylock et al.'s work supports the theory of typically wet regions of Europe becoming wetter with climate change, while typically dry regions would become drier. There is also a return to the work by van der Linden and Mitchell (2009), who reveal a seasonal sensitivity to the impact of climate change on precipitation – with greater amplification of aridity for Central and Southern Europe during the summer.

Disproportionality in the effects of climate change on European weather conditions are further discussed in the EEA report concerning storms and extreme weather, and snowfall. Historic data show that storms and extreme weather were and are prevalent in Northern Europe, the effect of climate change on this is predicted to intensify the contrast of this prevalence, with storm magnitudes falling in Southern Europe and increasing in Northern Europe. Predictions of how climate change will impact on snowfall is measured in the number of snowfall days that occur in a year. Calling on work by Vajda et al. (2011), projected snowfall days decrease by up to 25 per year, with greater bearing on mountainous regions and North Eastern Europe.

It has been demonstrated from the use of historic data and climate prediction models that the impact of climate change on particular weather conditions becomes complex at a regional level. Impact depends not only on specific locations, but on seasonal variation at that location. By reducing the scope for impact to a national level this complexity is propagated through to demonstrate greater disparity; that being said, the general effects of climate change on certain weather conditions for that region are also retained.

2.3. Predicted Data for Climate Change in Egypt

Egypt is one of the many countries that will be severely affected by global warming. Amongst highly populated countries, Egypt is regarded as the fifteenth most populated country in the world which causes man-made negative environmental consequences. Egypt will suffer from sea level rise, water scarcity, agriculture and food insufficiency and pressures on human health and national economy based on the effect of global warming. Along with the environmental consequences, global warming also negatively affects Egypt's Architectural Heritage. In attempt to preserve heritage buildings, this section summarizes the essential climate change predictions.

Table 2 - Projected climate change scenarios for Egypt for the next 20-40 years

Parameter	Scenario
Temperature	High contrast in seasonal temperatures. An increase in the mean annual temperature of between +0.5 to 4.5 °C. Greater impact of these scenarios fall on the South of Egypt.
Precipitation & Flooding	Annual and seasonal drying/warming signal. Reduction in rainfall.
Drought	A significant increase in temperature increasing the possibility of enhanced water losses. This might imply reduction in stream flows and stored water.
Sea Level Rise	Projected rise between 3 and 61 cm. Tidal range of about 20cm.
Storms	Difficulties in analyzing change in storminess

The United States Agency for International Development (USAID)(2015) predicted the following climate change in Egypt:

Temperature

- Current (based on historical climate conditions and recent trends, generally over the past few decades)

Annual average temperatures increase from about 20°C on the Mediterranean coastline to around 24°C on the Red Sea coastline, 25°C at Cairo, and 26°C further south at Aswan (UKMO, 2013). Typical daytime maximum temperatures in midsummer range from 30°C at Alexandria southward to 41°C at Aswan; while the corresponding north-south range in midwinter daytime maximum temperatures is 18°–23°C. There have been widespread warming trends over Egypt since 1960 with greater warming in summer (0.31°C per decade) than during winter (0.07°C per decade); statistical confidence is higher for the summer warming trend. Between 1960 and 2003, there has been an increase in the frequency of warm nights and a decrease in the frequency of cool nights, and a general increase in average summer temperatures. Nighttime temperatures (daily minimum) show a widespread positive shift in the distribution with fewer cool nights and more warm nights. Confidence is high throughout.

- Future: 2030 (generally 2020-2049)

The mean annual temperature in the country is projected to increase by 1.07°C to 1.27°C by 2030 for the RCP4.5 and RCP8.5 median model ensemble, and by 0.37°C and 0.61°C for the RCP4.5 and 8.5 10th percentile, and by 1.78°C and 2.11°C for the RCP4.5 and 8.5 90th percentile (CCKP). Maximum temperatures are projected to increase by 1.0°C to 1.22°C, and minimum temperatures by 1.09°C and 1.32°C for the RCP4.5 and 8.5 median ensemble.

- Future: 2050 (generally 2040-2059)

At midcentury, mean annual temperatures are projected to increase by 1.64°C and 2.33°C for the RCP4.5 and 8.5 median ensemble, by 0.81°C and 1.52°C for the RCP4.5 and 8.5 10th percentile, and by 2.62°C and 3.45°C for the RCP4.5 and 8.5 90th percentile, respectively (CCKP). Increases are highest in

summer months of July to September. Increases in the number of hot days (especially in summer), and decreases in the number of cool days are projected for the median ensemble by midcentury for the A2 and B1 scenarios. Over North Africa under the SRES A1B scenario, both annual minimum and maximum temperatures are likely to increase in the future, with greater increase in minimum temperature (IPCC, Climate Change 2014: Impacts, Adaptation, and Vulnerability. , 2014).

Precipitation and Flooding

- Current (based on historical climate conditions and recent trends, generally over the past few decades)

Annual average rainfall from 1961 to 1990 was 41.8 mm. About half of the yearly precipitation falls from December through March (CCKP). Precipitation is generally very low throughout the country although along the Mediterranean coastline it averages more than 200 mm/yr (UNDP, 2013). Precipitation rates drop quickly as one moves away from the coast and most of Egypt receives only about 2 mm of precipitation per year. Most of Egypt is a desert and is classified as arid (except for the Mediterranean coast, which is semi-arid). Given lack of precipitation data, there is low statistical confidence regarding historical trends (IPCC, Climate Change 2014: Impacts, Adaptation, and Vulnerability. , 2014). There is a small region of drying in the northeast, where confidence in the signal is higher. There is evidence that the severity and frequency of flash flooding across Egypt has increased in recent years. Over the last few decades the northern regions of North Africa have experienced a strong decrease in the amount of precipitation received in winter and early spring.

- Future: 2030 (generally 2020-2049)

The median ensemble runs for RCP4.5 and 8.5 indicate an average annual rainfall change of 0 mm/day, and 0.1mm/day, by the middle of the 2030s [USGS]. By 2030, the RCP4.5 10th percentile (-90%), median (-2%), and 90th percentile (102%) ensembles for mean annual precipitation indicate high uncertainty in the direction and amount of change across the models [CCKP]. These results are similar to RCP8.5 (-92%, -2%, and 121%).

- Future: 2050 (generally 2040-2059)

A reduction in rainfall over northern Africa is very likely by the end of the 21st century (IPCC, Climate Change 2014: Impacts, Adaptation, and Vulnerability. , 2014). The annual and seasonal drying/warming signal over the northern African region (including Egypt) is a consistent feature in the global and the regional climate change projections for the 21st century under the A1B and A2 scenarios. Rainfall projections are highly uncertain, but indicate slight reductions in rainfall in Egypt for most months by midcentury for the median ensemble RCP4.5 and RCP8.5 scenarios (CCKP). However, the RCP4.5 10th percentile (-101%), median (-4%), and 90th percentile (98%) ensembles for mean annual precipitation indicate high uncertainty in the direction and amount of change across the models. These results are similar to RCP8.5 (- 107%, -7%, and 135%). The IPCC AR4 found consistency across GCMs that wet extremes could increase. There is uncertainty regarding the magnitude to which flood season discharge into the Nile River could be affected by climate change and GCMs are not consistent in simulating the same signs of change (UKMO, 2013).

Drought

- Current (based on historical climate conditions and recent trends, generally over the past few decades)

Rainfall variability within Egypt is almost inconsequential, given that the country receives very little rainfall, as well as the fact that its agriculture is irrigated and not rain-fed [UNEP]. Variability in Nile flows are moderated by the High Aswan Dam. The dam has one year's worth of storage capacity, to help in handling periodic droughts, although Egypt remains vulnerable to multiyear droughts.

- Future: 2030 (generally 2020-2049)

Estimates are highly uncertain and information is not readily available. Consider future drought conditions based on the most extreme past experience.

- Future: 2050 (generally 2040-2059)

There is considerable uncertainty with regard to the projections of rainfall—both over Egypt as well as over the principal headwaters of the Nile [UNEP] (OECD, 2004). There is agreement across climate models that temperatures are projected to increase significantly under climate change, increasing the possibility of enhanced water losses from 3 September 2015 evapotranspiration—particularly given the arid climates of Egypt and Sudan— which might imply reduction in stream flows and stored water.

Sea Level Rise and Storm Surge

- Current (based on historical climate conditions and recent trends, generally over the past few decades)

Sea levels have risen across the Mediterranean by an average of more than 3.1 mm each year since 1992, although records from further back indicate considerable local variability (Verner, et al., 2013). One array of tide gauges indicates that since 1990, Mediterranean Sea levels have risen at a rate 5–10% faster than the 20th- century mean rate. Measurements on the Egyptian coast indicate that sea level is continuously rising at a rate of 1.8 and 4.9 mm/year with an average of 3 mm/year (Frihy & El-Sayed, 2013). The relative sea level shows an upward increasing trend as a result of land subsidence and eustatic sea level. In recent years (December 2003, December 2010, and January 2011), major storms have struck the Mediterranean coastline of Egypt and have produced—during a short period—a surge of up to about one meter above the mean sea level.

- Future: 2030 (generally 2020-2049)

Simple interpolation of a minimum and a maximum sea level rise scenario indicates that by 2030, the total, Mediterranean basin averaged sea level rise will be between 0.07 and 0.18m (Galassi & Spada, 2014). One study used low (0.07m), medium (0.11m), and high (0.25m) scenarios for sea level rise projections in the delta region in the year 2030 (El-Nahry & Doluschitz, 2010).

- Future: 2050 (generally 2040-2059)

Sea levels are projected to rise between 3 and 61 cm this century, depending upon local heat and salinity levels of the Mediterranean [WB]. Sea level rise projections in Egypt's delta are exacerbated by considerable land subsidence (5.0 cm/year), and a tidal range of about 20 cm (El-Nahry & Doluschitz, 2010). One study used low (0.11m), medium (0.20m), and high (0.40m) scenarios for midcentury sea level rise in the delta region (El-Nahry & Doluschitz, 2010). Another study used low (0.10m) and high

(0.26m) scenarios for sea level rise in the Mediterranean basin (Galassi & Spada, 2014). Particular risk areas in the Alexandria region are: Mandara and El Tarh (east of the city), and risk areas in the Nile Delta region are: The Manzala Lagoon barrier, east and west of the Rosetta City, Gamil, and the Tineh plain (Frihy & El-Sayed, 2013).

Winds and other storms

- Current (based on historical climate conditions and recent trends, generally over the past few decades)

Egypt is not impacted by tropical cyclones (UKMO, 2013). Climate hazards include dust storms in spring and early summer, which are a dry and dust-laden "Khamsin" wind that, from time to time, carries very hot air northward into northern Egypt ahead of weak cyclonic disturbances in the Mediterranean. Increased severity and frequency of sand storms and haze have been documented.

- Future: 2030 (generally 2020-2049)

Estimates are highly uncertain and information is not readily available. Consider future winds and storms based on the most extreme past experience.

- Future: 2050 (generally 2040-2059)

There are difficulties in analyzing changes in storminess, given the lack of robust historical analysis of local or global land surface winds or storminess currently available (UKMO, 2013).

Moreover, in a study of predicted trend of fungal keratitis in Egypt, they predicted an in annual temperature in Egypt using the General Circulation Model are 1°C (standard deviation (SD) 0.15°C) by the year 2030 and 1.4°C (SD 0.22°C) by the year 2050 (Saad-Hussein, El-Mofty, & Hassanien, 2011). In addition, predictions for CO₂ emissions are shown in figure 10.

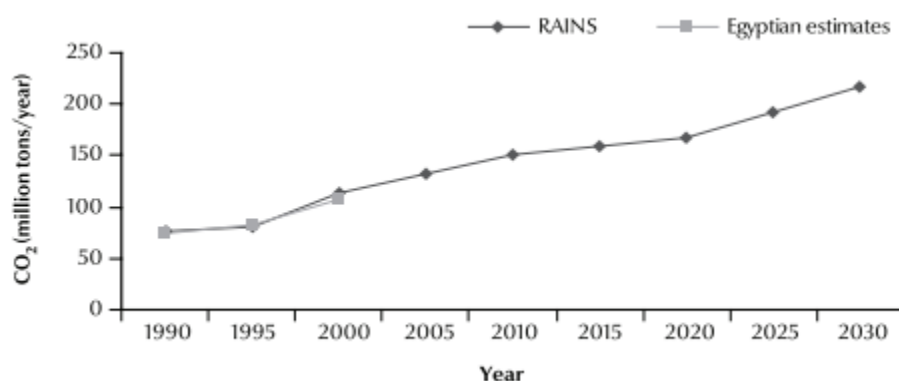


Figure 10 Predicted emissions of carbon dioxide (CO₂) in Egypt 1990–2030 and data from the Regional Air Pollution Information and Simulation (RAINS) model. (Hassanein, 2003).

2.4. Predicted Data for Climate Change in the UK

Cassar (2005) provides substantial insight into the potential and perceived impact of climate change in the historic environment of the UK. Her work investigates climate change scenarios for the UK across the next 50 – 80 years, and are determined using UKCIP02 climate projection methodology (Hulme, 2002). Scenarios with a moderate to high confidence are summarised in table 3.

Table 3 - Projected climate change scenarios for the UK for the next 50 – 80 years

Parameter	Scenario
Temperature	High contrast in seasonal temperatures. An increase in the average annual temperature of between +1 to +5 °C. Greater impact of these scenarios fall on the South East of England.
Precipitation	High seasonal contrast: Drier summers, wetter winters. Decreased snowfall. Impact of climate change on precipitation is not region specific.
Humidity	Increase in specific humidity. Decrease in relative humidity in the summer. Impact of climate change on humidity is not region specific.
Soil Moisture	South East England to experience a significant decrease in soil moisture content during the summer and autumn. North West England to experience a significant increase in soil moisture content during the winter and spring.
Sea Level Rise	Significant regional variation in the rising sea levels. Persisting trends in vertical land movement. Reduction of return periods by an order of magnitude.
Storms	Increased frequency of deep winter depressions.

Precipitation

It is predicted that the in the UK precipitation levels will rise in general rise in the winter by around 33% but in terms of annual rainfall as a whole this is the subject of further research and has yet to found to be predicted to be substantially difference from the 1960-90 baseline. (Met Office 2011). Whilst actual average rainfall may remain unchanged the number of intense downpours are likely to increase as well as a rise in the predicted maximum daily rainfall. Some parts of Southern England may also see a rise in the number of occasions of rainfall (Sabbioni et al. 2010).

Large changes are expected in summertime precipitation, down to around –40% (–65 to –6%), are seen in parts of the far south of England. Changes close to zero (–8 to +10%) are seen over parts of northern Scotland. (Jenkins et al. 2010)

Temperature Change

The UK is predicted to experience change in average annual temperature by 2100 from 1960- 1990 baseline climate of around 3°C in the south and 2.5°C further north (Jenkins et al. 2010)

The average daily maximum temperatures will rise throughout the UK. Increases in the summer average temperatures are up to 5.4°C in parts of southern England and 2.8°C in parts of northern Britain. Increases in temperatures in the winter are less, at an average of around 1.5°C to 2.5°C across the UK. (Jenkins et al. 2010)

The average daily minimum temperature will see and increase on average in winter by about 2.1°C to 3.5°C. In summer it increases by 2.7°C to 4.1°C (2.0 to 7.1°C), with the biggest increases in southern Britain and the smallest in northern Scotland. (Jenkins et al. 2010)

Storms

According to research by the Met Office and the Association of British Insurers the amount of windstorms affecting the UK:

“With a global temperature rise of 1.5°C, the number of storms over the UK generally decreases with the largest decrease in storm occurrence over the southwestern UK. Under a global temperature increase of 3.0 and 4.5° C, the number of storms over the UK generally increases by up to 15%” (Robinson et al. 2017)

This data is based on baseline data set from 1995-2004. There are exceptions to this general rule to be found in the southern UK, where the opposite is true, less storms are predicted with rises in temperature. The largest predicted rises in number of windstorms are predicted in the central UK including Birmingham, Liverpool and Sheffield.

Wet frost

Wet frost relies on two weather conditions; there must have been more than 2mm rainfall in the recent days, with the temperature also above 0°C, followed immediately by a period with temperature below -1°C. These scenarios are predicted to decrease in northern Europe including the UK. This will lead to less freeze thaw cycles (Sabbioni et al. 2010).

Wind driven rain

It is important to make the distinction between “normal” rain and wind driven rain (WDR). Wind driven assumed to have a component of horizontal motion, i.e. it is not simply falling vertically. The horizontal action is caused by the wind. WDR will pose different threats to heritage buildings when compared to vertical rain, in that the rain may fall directly onto the walls rather than the roofs, which are less sensitive to rainfall. This will lead to significant moisture penetration into porous wall materials such as stone and brick. This can cause some materials to fail more rapidly than expected, especially when coupled with frost, causing spalling. A metric has been developed to measure WDR, combining the two components of wind and rain to form the Wind-driven rain index (mm.m/s.year). This value is set to rise in the UK. (Sabbioni et al. 2010)

Wind

According to UKCP09 the wind speed in the summer months the UK is set to change over the current period to 2080 by around 0m/s to 0.2m/s. This is an insignificant change in wind speed especially when we consider that the average summer wind speeds are in the order of 3.6 -5.1 m/s. The winter months are predicted to see net zero changes in wind speed. (Jenkins et al. 2008)

Solar Radiation

The mean cloud cover in the summertime for the UK is set to decrease by up to -18% (-33 to -2%) in parts of southern UK, this will lead to increased levels of solar radiation onto buildings, (+16 Wm⁻² (-2 to +37 Wm⁻²). However the cloud cover is predicted to rise slightly in far northern parts of Scotland which will lead to lesser amounts of solar radiation by up to +5% (zero to +11%).

During the winter months for the UK the cloud cover is expected to remain largely the same with changes expected to be in the range of –10 to +10%, thus solar radiation is expected to remain largely unchanged during this period.

Relative Humidity

Relative humidity in the summertime is expected not to change significantly, decreases by around –9% (–20 to 0%) in summer in parts of southern England — by less elsewhere. The winter will see even less change, around a few percent in general across the UK.

2.4.1. Climate Models

The climate change methodology of UKCIP02 used to model the future climate change scenarios in Cassar’s work is just one method of many that have been considered to model future climates. Table 4 lists just a few of these models used to predict climates in the UK.

Table 4 - Models used in predicting climate change scenarios in the UK

Model	Source
HadCM3: Hadley Centre Coupled Model	Gordon et al., 2000
UKCIP02: UK Climate Impacts Programme	Hulme, 2002
UKCP09: UK Climate Projections	Murphy et al., 2009
CMIP5: Coupled Model Intercomparison Project	Taylor et al., 2012

Recent efforts to model regional projections for climate change is found in the University of Exeter’s Prometheus programme (Eames et al., 2011), which uses the UKCP09 model to predict weather up to 2080 for over 45 different locations across the UK. The variation in these predictions also support the projections discussed by Cassar.

Data from the Prometheus project can be used to predict how the climate will change at the locations of the two UK case studies: Manchester and Bristol. Weather profiles for these location are provided at 4 intervals – an analysis of the current weather given historical weather patterns (1951 – 1990), for 2030, 2050 and 2080. Each of the weather profiles takes into account the following weather parameters: dry bulb & dew point temperatures, relative humidity, atmospheric pressure, solar incidence, wind speed & direction and precipitation.

An example of these weather data is shown in the following figures (11-17), which depict the annual temperature, humidity and precipitation profiles for both Manchester and Bristol.

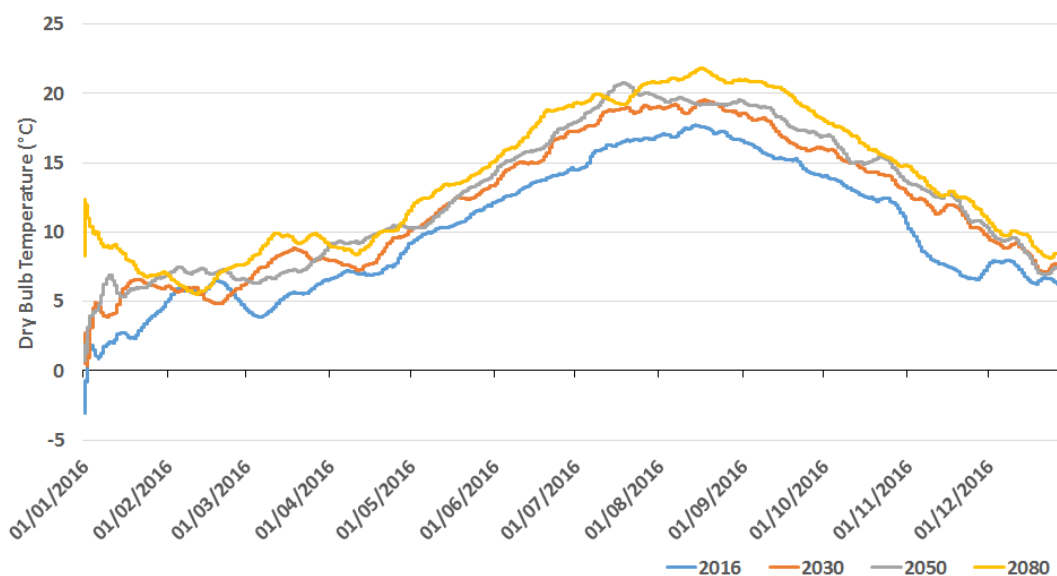


Figure 11 Simulated annual dry bulb temperatures for Bristol in 2016, 2030, 2050 and 2080, displayed with a monthly moving average.

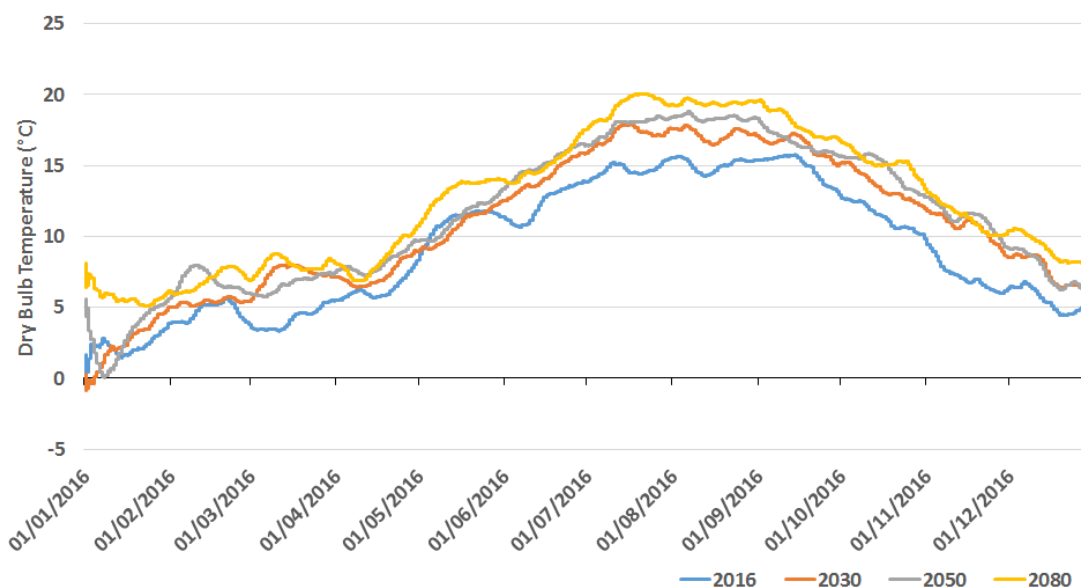


Figure 12 Simulated annual dry bulb temperatures for Manchester in 2016, 2030, 2050 and 2080, displayed with a monthly moving average.

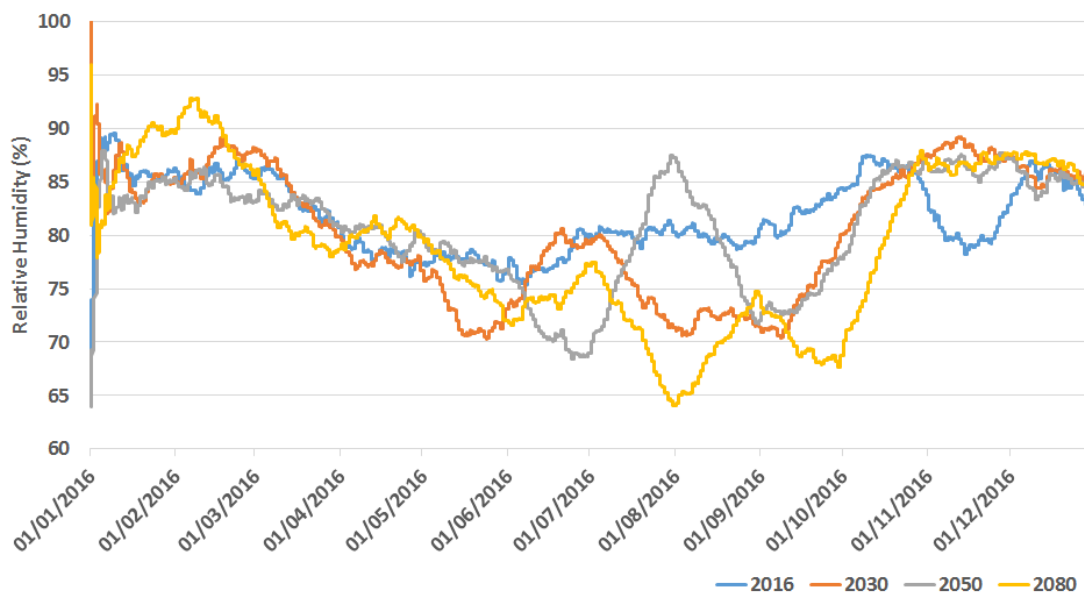


Figure 13 Simulated annual relative humidity for Bristol in 2016, 2030, 2050 and 2080, displayed with a monthly moving average.



Figure 14 Simulated annual relative humidity for Manchester in 2016, 2030, 2050 and 2080, displayed with a monthly moving average.

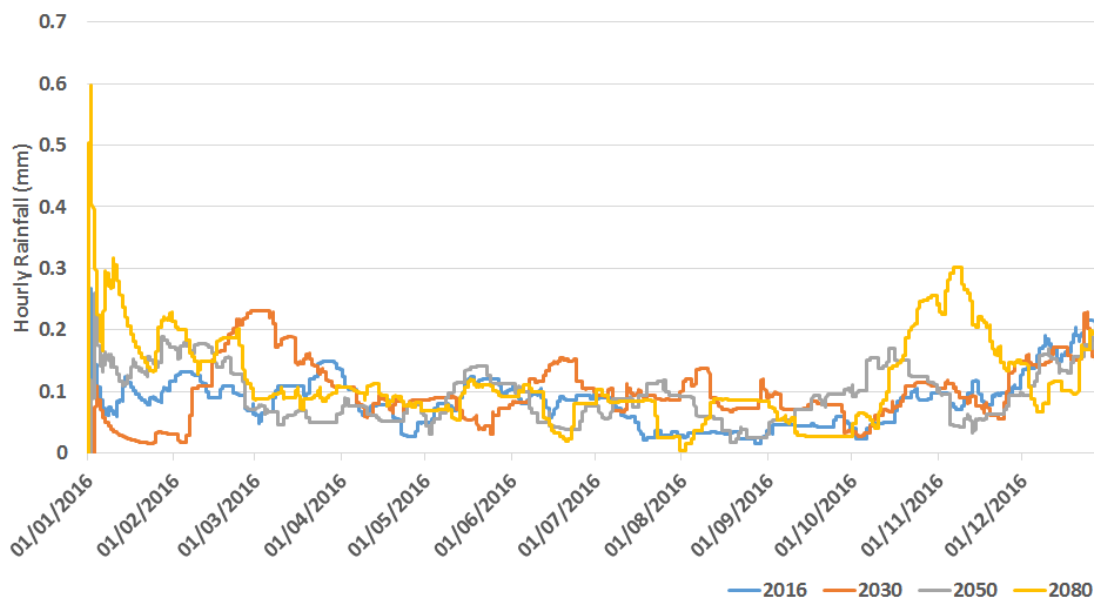


Figure 15 Simulated annual rainfall for Bristol in 2016, 2030, 2050 and 2080, displayed with a monthly moving average.

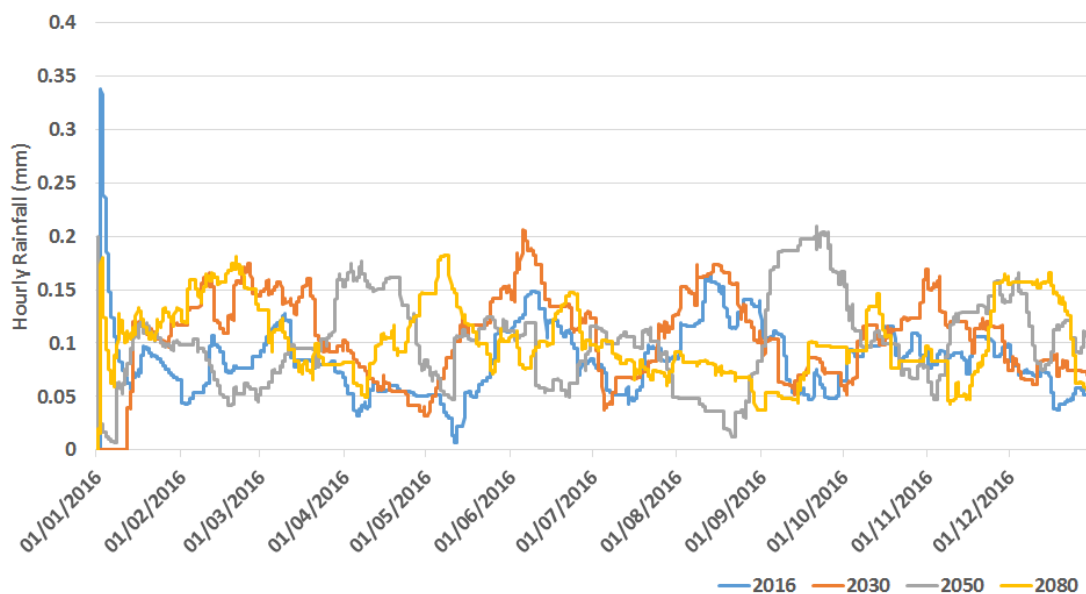


Figure 16 Simulated annual rainfall for Manchester in 2016, 2030, 2050 and 2080, displayed with a monthly moving average.

Annual temperatures in both Bristol and Manchester observe an increase over time. On average, the peak temperature for Bristol increases from 17.7°C to 21.9°C, while the peak temperature for Manchester increases from 15.8°C to 20.1°C. These variations in temperature could be responsible for a shift in thermal comfort, resulting in overheating in the summer.

Humidity does not display dramatic shifts similar to temperature – however the notion of summers having lower relative humidity, as suggested in Table 1, can be seen in these data and is accentuated in the Bristol data.

It is proposed that rainfall is likely to increase over time – this is demonstrated in the simulated data for both Bristol and Manchester. The total annual rainfall for Bristol increases from 798mm to 1008mm, while in Manchester this total annual rainfall increases from 721mm to 880mm. In each case the rise in precipitation totals approximately 20%. This additional rainfall would evidently put strain on any heritage building's water goods, were they ill-maintained or inadequate for supporting this surplus water.

The results of these simulated local weather data agree with the suggestions discussed by Cassar. While the increase in temperature over time will have an impact on the energy performance of heritage buildings and the thermal comfort of the building's occupants, the key concern lies with the increase in precipitation over time. The demonstrated increase in rainfall of approximately 20% has implications on a number of aspects. Failure of water goods in the handling of this surplus rainwater would lead to increased risk of flooding within these buildings. This not only poses a risk to the contents of a building, but also to the building themselves. Poor drainage of floodwater would promote the earlier discussed upshots of ground heave and subsidence, putting the building at serious risk of permanent damage.

Given the risk of climate change impact on both energy performance and structural integrity of heritage buildings, it is important then to understand how to monitor, measure and mitigate these impacts for the sustainable preservation of heritage buildings.

3. Climate Change and World Heritage

World Heritage properties are affected by the impacts of climate change at present and in the future. Their continued preservation requires understanding these impacts to their Outstanding Universal Value and responding to them effectively.

World Heritage properties also harbour options for society to mitigate and adapt to climate change through the ecosystem benefits, such as water and climate regulation, that they provide and the carbon that is stored in World Heritage forest sites. Cultural heritage, on the other hand, can convey traditional knowledge that builds resilience for change to come and leads us to a more sustainable future.

World Heritage properties serve as climate change observatories to gather and share information on applied and tested monitoring, mitigation and adaptation practices. The global network of World Heritage also helps raise awareness on the impacts of climate change on human societies and cultural diversity, biodiversity and ecosystem services, and the world's natural and cultural heritage.

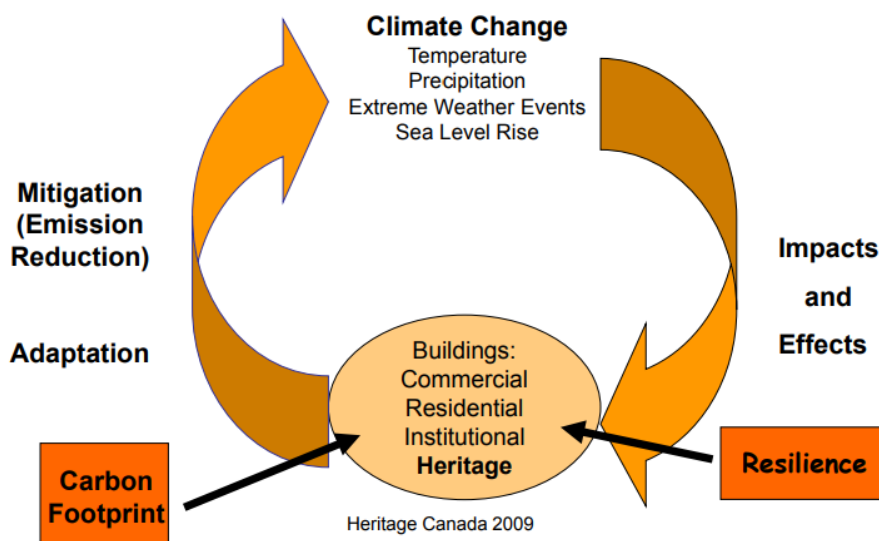


Figure 17 Climate Change and Heritage, (Heritage Canada, 2009).

3.1. Effect of Climate Change on Heritage Buildings in Egypt

3.1.1. Building Structures and Infrastructure

Climate change affects heritage buildings on many levels. In addition to affecting the building’s material and structure, it also has a direct effect on the indoor climate and the cultural aspect of the building. Climate change includes various factors that affect the lifespan and durability of architectural heritage materials, elements and buildings. The physical existence of the building depends on the type of impact it is subjected to. Climate has a range of impacts from decay to weathering to natural disasters. The following effects were discussed as follows (Sabbioni, Brimblecombe, & Cassar, 2010):

1. Wind effects
 - Loading and mechanical damage of structures.
 - Weather and wind abrasion affect building materials and could cause significant changes to exterior parts of the structure.
 - Increase/decrease the chemical action of water, air and gases which may increase the transport of air into or out of a material.
 - Pollutant deposition, biological colonisation, cycles of drying and wetting and mechanical wear of surfaces.
2. Landslides

In landslide, a structure is displaced from its original position and in many cases is overturned.

3. Weathering effects

They involve effects caused by light, heat, water, air wind and air pollutants.

4. Radiation

Objects directly exposed to solar radiation exhibit damage and failure due to heat and UV radiation or light. Ionic radiation which has stronger energy than non-ionic radiation may cause chemical change in materials, for example netting or cleavage of polymers. Non-ionic radiation exhibits mostly thermal effects.

5. Temperature

Temperature is considered one of the worst climatic parameters. In Egypt, temperature ranges from 6°C to about 42°C. All building materials are sensitive to temperature as the majority of building materials can expand with an increase in temperature and contract with a decrease in temperature.

6. Water

Water together with temperature or other parameters, can cause decay. Egypt doesn't experience much snow or rain however water also can be in the form of condensation or water trapped in hollows or voids, or as ground water which can seep carrying corrosive substances or compounds.

3.1.2. Material Deterioration

3.1.2.1. Outdoor Stone and Brick

Parameters such as temperature change, atmospheric moisture change, sea level rise, wind, and desertification as a result of climate change all help in the damage of heritage building materials. According to (Sabbioni, Brimblecombe, & Cassar, 2010), the most important damage occurrences found to exist in Heritage Buildings that require understanding in order to provide appropriate protection and maintenance are:

1. Surface recession

The chemical attack induced by the effect of clean and acid rain and the dry deposition of gaseous pollutants occurring between precipitation events affects mainly carbonate stones and gives rise to surface recession.

2. Blackening

The external surface of any building in urban polluted environment is unavoidably destined to be covered with layers that assume a grey to black colour and are generally called 'black crusts'. These, according standard protocols and glossary, are deteriorated surface layers of stone material; they can have variable thickness, are hard and fragile and can detach spontaneously from the substrate, which, in general is quite decayed (Toniolo, Zerbi, & Bugini, 2009).

3. Thermoclastism

It is the process of differential thermal expansion and contraction of surface mineral grains and interstitial salt deposits (such as nitrates) in response to long- and short-term temperature fluctuations at the material surface, due to solar radiation effect under natural exposure conditions.

4. Bio-deterioration

Biodeterioration is caused by human activities through land-use and land-cover changes, soil, water and air pollution, intensive eco-systems management, selective species exploitation, introduction of non-native species, etc.

3.1.3. Impacts of climate change on Cultural Heritage

(Sabbioni, Brimblecombe, & Cassar, 2010).

Atmospheric moisture change

Risks:

- Flooding (river, sea)
- Intense rainfall
- Changes in water table levels
- Changes in soil chemistry
- Ground water changes
- Increase in time of wetness
- Sea salt chlorides

Impacts:

- Loss of stratigraphic integrity due to cracking and heaving from changes in sediment moisture
- Loss of data preserved
- Depletion of oxygen in water accelerating microbial decomposition of organic materials
- Physical changes to porous building materials and finishes due to rising damp
- Damage due to faulty or inadequate water disposal system; historic rainwater goods not capable of handling heavy rain and often difficult to access, maintain and adjust
- Subsoil instability, ground heave and subsidence
- Relative humidity cycles/shock causing splitting, cracking flaking and dusting of materials and surfaces
- Corrosion of metals

Temperature change

Risks:

- Seasonal extreme events (heat waves)

Impacts:

- Deterioration of facades due to thermal stress
- Biochemical deterioration

- Changes in 'fitness for purpose' of some structures. For example, overheating of the interior of buildings can lead to inappropriate alterations to historic fabric due to the introduction of engineered solutions
- Inappropriate adaptation to allow structures to remain in use.

Sea level rises

Risks:

- Coastal flooding
- Sea water incursion

Impacts:

- Coastal erosion/loss
- Permanent submersion of low lying areas
- Sporadic introduction of large masses of 'strange' water to the site, which may disturb the metastable equilibrium between artefacts and soil
- Population migration
- Disruption of communities
- Loss of rituals and breakdown of social interactions

Wind

Risks:

- Wind-driven sand
- Wind-transported salt
- Winds, gusts and changes in direction

Impacts:

- Structural damage and collapse
- Static and dynamic loading of historic structures
- Deterioration of surfaces due to erosion

Desertification

Risks:

- Drought
- Heat waves
- Fall in water table

Impacts:

- Erosion
- Salt weathering
- Impact on health of population
- Abandonment and collapse
- Loss of cultural memory

Climate and pollution acting together

Risks:

- pH precipitation
- Changes in deposition of pollutants

Impacts:

- Stone recession by dissolution of carbonates
- Blackening of materials
- Corrosion of metals

3.1.4. Conclusion

As seen before Climate Change has various effects on Heritage Buildings. The following table (Table 5) summarizes those changes and their effects.

Table 5 Summary of Climate Change effect on Heritage in Egypt

Parameter	Scenario	Effect on Physical Aspect	Effect on Cultural Aspect
Temperature	High contrast in seasonal temperatures. An increase in the mean annual temperature of between +0.5 to 4.5 °C.	-Expanding and contracting of material. -Thermoclastism (p. 29) -Biochemical deterioration	-Deterioration of hisotric facades -Inappropriate alterations to historic fabric due to introduction of engineered solutions -Inappropriate adaptation
Precipitation & Flooding	Annual and seasonal drying/warming signal. Reduction in rainfall.	-Decay -Biodeterioration -Surface Recession	-Loss of stratigraphic integrity -Cracking & heaving -Corrosion of metals
Drought	A significant increase in temperature increasing the possibility of enhanced water losses.	-Loading and mechanical damage of structures -Changes to exterior parts	-Abandonment and collapse -Loss of cultural memory
Sea Level Rise	Projected rise between 3 and 61 cm. Tidal range of about 20cm.	-Erosion -Metastable equilibrium between artefacts and soli	-Permenant submersion of low lying areas -Disruption of communities -Loss of rituals

3.2. Effect of Climate Change on Heritage Buildings in UK

As predicted climate changes were previously discussed by Cassar, he goes on to discuss how these predicted scenarios might impact on historic buildings in the UK. This is relevant to heritage buildings as they often exhibit a great deal of longevity and are therefore subject to the same risk of damage due to climatic effects. These risks are discussed:

Temperature / Humidity Variation

The overall increase in temperature in the UK is seen as a moderate risk to heritage buildings. The structural integrity of certain buildings that are susceptible to material deterioration at higher temperatures is a key concern. Decomposition of wooden structural supports would worsen with the coupling of increased humidity, moisture content of materials and higher temperatures.

This coupling of moisture and temperature also encourages the decay of wooden structures and supports. Pests and fungus growth are worrisome, as both lead to the destruction of wooden materials within a building. Dry rot as an example can cause embrittlement of supports, weakening the overall structure of the building.

Thermal comfort of building occupants is also a concern. With rising annual temperatures, a shift in thermal comfort within heritage buildings is certain. The magnitude of this impact however, depends on the thermal performance of specific buildings.

Precipitation

Increased seasonal rainfall puts pressure on the drainage systems of historical and heritage buildings. These systems were typically designed to sustain drainage for a lower rainfall than is anticipated with climate change and so any surplus precipitation is likely to be problematic. Flooding can result from inadequate water goods during high levels of rainfall, the impact of this falls not only on damage to property within heritage buildings, but on the structure of the building as well.

Soil Moisture Content

Although the impact of climate change on soil moisture content between the South East and North West of England varies, the effects on heritage buildings are similarly destructive. The reduced moisture content in the South East over summer and autumn could result in the retraction of soil away from the foundations of a building. This would not only have a negative impact on the energy performance of the building, but would expose the building elements to damage. Where increased soil moisture content is seen for the North West of England, ground heave is a possibility, and with poor drying of saturated soil is the risk of subsidence.

Sea Level Rise

With the projected increase in sea level and reduced return periods, coastal buildings in particular are under threat from coastal erosion.

Storms

The increased frequency of storms intensifies the effects of heavy rainfall and the complications due to inadequate drainage systems. The effects of property flooding are exaggerated given the threat of greater storm frequency.

Cassar discusses the perceived impact of climate change on historical buildings by questioning estate managers for historical sites across the UK. The greatest concern was attributed to the predicted increase in rainfall. Comments were made on the inadequacies of water goods at historical sites, the potential for flooding and the consequences of this flooding. Though an argument was made against

inadequate water goods, a concern of failed drainage materials vs. improper maintenance were also raised. Secondary concerns for historical site managers were that of fluvial and coastal flooding, and the resulting impact on subsidence and ground erosion. Wind, as a cause of building erosion, was also discussed as a key concern. Further impacts of climate change on historical buildings such as temperatures and humidity variation did not receive comparable concerns.

4. Monitoring the effects of Climate Change on Heritage Buildings

In this section, only factors monitored in the project will be mentioned. The project is collecting the following data and monitors and logs the following variables:

The aims of this section are as follows:

1. To provide a brief and basic overview of climatic conditions and the changes expected in the future. This will be an overview of the two regions covered by this project; Egypt and the UK.
2. What these changes may mean for heritage buildings in terms of damage to the fabric
3. How can this deterioration be measured and possibilities for mitigation

4.1. Laser Scanned Point Cloud Data

The process of scanning buildings using laser equipment is well recognised and has been used for many years. This project used a Leica C10 Scanstation to provide point cloud data and textured images. These were gathered for several of the properties from ground levels. In terms of heritage preservation the usage of the technology has specific benefits. The point clouds represent an the surface of the measured building within an accuracy of between 2-4mm (Leica Geosystems 2011). This allows an accurate dataset to be built of the external and internal faces of facades, internal partitions and any other built in features to be catalogued such as architraves etc. Further to this these point clouds can be used recorded not only in 3 dimensions, but also over time to allow buildings to be compared over a number of periods. The project has taken only one record of the selected buildings, but the portal will allow for updated point clouds to be updated and compared. It is this comparability that makes laser scanning particularly useful for studying changes in buildings as discussed below.

4.1.1. Deflection

Deflection can occur in many different building materials and is the process whereby the element, such as a supporting timber is bent or stretched past its original design performance. An example of this may be a timber lintel supporting a window opening; if the timber is subject to rot or excessive loading then it will deflect.

4.1.2. Thermal Stress

This process is the result of the expansion or contraction of a building material due to the climate in which it is situated. Some materials can expand a great deal in hot climates, these are said to have a high coefficient of thermal expansion where some will hardly expand at all, and are known to have a low coefficient of thermal expansion. Other materials such as water when exposed temperatures less than 0 degrees C will expand as ice crystals form, this has an impact in materials which have water present also.

4.1.3. Deterioration

Deterioration can occur in many materials including stone, timber and brick. The rate at which the materials decay is a function of the climate, the chemical composition of its surrounding and the actual material itself. For this reason some buildings may deteriorate at different rates during different periods. This makes for a very dynamic situation, and one which must be observed as the climate changes and the atmosphere becomes polluted. Failure to observe this effect closely may lead to significant damage to the entire building and not just the area in which the deterioration is greatest.

4.1.4. Damage to buildings

Damage to buildings is to be expected whether a heritage structure or not. In buildings where heritage is a feature then all details can be valuable and not just the ones in plain sight. Items such as ornamental features at street level and ornate fencings can easily be damaged by the public and often go unchecked. Other damage to buildings may include intended damage such as graffiti failure to observe and record a building before this damage takes place may end in the reinstatement work being out of context with the original building.

4.1.5. Extraneous growth/vegetation

Buildings can be susceptible to nature of all types, however one particularly damaging aspect is that of biological growth. This can be in the form of moss growth on tiled roofs, defecation by birds and items such as unwanted foliage growing in the building fabric. These are all defects which overtime can cause significant structural issues to the fabric.

The defects described above can be readily identified with carefully captured and studied point cloud data. Longitudinal monitoring of this structured dataset will assist in carrying out maintenance in a timely manner, and could help prevent further structural damage occurring. This is particularly useful where a building is clad/coated and defects may not be easy to spot to the naked eye. This technique is also useful to identify if the movement is progressive (and a significant issue) or has stabilised (and may have been a built in defect or no longer an issue). Various techniques can be used to illicit these changes in the building, point cloud scans can be used to spot historical defects in buildings such as non- verticality of walls this is well documented in by Vacca, who created many scans of historical buildings with the aim of viewing deformation in the structure the point cloud data was used to generate digital surface models (DSM) of the facades and floors. The DSM were illustrated in colours representing deviation from plumb, and also contour lines (Vacca et al. 2016).

Another use for point cloud data is to view the data over a period of time to observe developing defects such as deterioration or damage between two different time periods.

4.2. Photogrammetry

Photogrammetry has been used for a number of years in heritage and conservation project to capture the both the geometry and surface texture of objects and whole buildings. The process, when compared to that of laser scanning is relatively straightforward and cost effective. Photogrammetry is carried out by firstly capturing a series of high resolution photographs from a variety of different angles. A software package is then used to create a 3d model of the subject. These 3d models can be output to a wide range of formats (including point clouds) for further analysis or display. A full and detailed

description of this process has been created by Remondino (Remondino 2011) A recent innovation in this area has been the addition of a unmanned aerial vehicles (UAV) or drone, to the process. This allows imaging to be taken from the air which aids in surveying roofs and features such towers etc. An added heritage benefit of the photogrammetry process (although generally related to the external faces of the elements) is that a full set of high resolution photos are also captured of the building which may prove useful.

4.3. Uses of Photogrammetry and Laser Scanning together

Although similar outputs can be generated by photogrammetry to that of laser scanning, the results are of a different degree of accuracy. The differences between the two methods using an example from the Joule House project is given in Table 5.

Table 6 - Comparison between Laser Scanning and Photogrammetry Techniques

Features	Photogrammetry	Laser Scanning
Accuracy levels	Data to be added from Research paper	Data to be added from Research paper
Output options	Textured mesh, point cloud	Point cloud/CAD
Equipment cost	£1000	£45,000
Survey cost (contractors market rate)	£500	£1000
Time taken for survey	2 hours	Data from JH example

Given that some of the outputs and uses of photogrammetry overlap with laser scanning an overview of the additional uses for this technology are given below:

4.3.1. Discolouration

The effects of the climate and the ageing process generally in building materials can often be recognised in discolouring or staining of the fabric. Examples of this are staining due to algae growth on surfaces or salt staining to masonry structures. These instances are not damaging the structure as such, but forming a thin layer on top. This is not easily recognised using point cloud data only, but can be readily observed by the human eye, and thus photographs. Thus photogrammetry provides a “time stamped” map of the extent of these issues in which can easily be measured and quantified as the models are spatially correct. This allows one period to be compared with another, and also can provide a photographic record of the building in its original condition if possible, allowing for restoration work to be carried out later.

4.3.2. Roof studies

A weakness of laser point scanning is that it is generally carried out from a ground based station, and thus can miss some important raised sections of the building including towers, chimneys and roof structures. All of these can have significant heritage value and all are vulnerable to climatic changes, such as changes in prevailing winds and wind driven rain.

4.3.3. Changing Landscapes

Drone surveys in particular, couple with photogrammetric techniques can make the task of mapping large portions of land, for instance gardens and structures surrounding heritage buildings, whilst also providing context to the building itself, landscapes can change quickly due to coastal erosion and other climatically affected conditions, as such to be able to view this movement from an aerial view point, using time series imagery may help preserve heritage assets before they are damaged.

4.4. Air Permeability

Air permeability testing, was carried out on Cluster Office and Joule House, these buildings were found to have air permeability rates in line with what is expected of buildings of this age.

The air permeability of a building is a measure of how air tight it is. Several factors can influence this measurement, such as holes/cracks in the fabric form service entry points, leaky windows, porous materials and in built ventilation systems. The rate of air permeability is measured (in the UK, although similar methods are used worldwide) using a fan which mounts in a door that is placed in an external frame temporarily. This fan creates either a negative or positive pressure inside the building, a calculation can then be made given the speed of the fan, on how many holes there are in the external fabric of the building (ATTMA 2010). Buildings which are have a higher rate of permeability are more susceptible to higher rates of heat loss through convective heat transfer, this means that as wind speeds and gust strength increases in the area directly surrounding a building then then greater quantities of heat loss will occur in during the heating months (Labat et al. 2013). This is due to differentials in pressure being creating across the structure which will extract warm air from the building, to be replaced with cooler air. The permeability of a heritage building may also change over time, this process is well not well documented in the literature but is well documented in studies that have been carried out over successive years in newly built homes, with permeability rates increasing in over 65% of buildings tested (Phillips et al. 2011), and one might suggest that this is replicated in heritage buildings. The reasons for this increase may be that cracks are appearing and/or growing in buildings, that maybe linked to changes in climatic conditions such as freeze thaw or action of thermal stress or that fabric is deteriorating around windows etc. As these changes can happen over a period of time it is important to measure these on regular occasions. This can be added to the HBIM dataset.

4.5. U-Value Measurements

U value measurements can assist in the determination of how energy efficiency an element of a building is, generally walls. A U value is determined as the thermal transmittance of a building element (ISO 2014), the figure is higher when then element has poor thermal performance and lower when thermal performance is good. U values are a valuable tool for assessing not only the energy performance of buildings, but also measuring any changes that have been made, for instance the addition of insulation to a wall. In terms of heritage buildings, the measurement of the thermal properties of an element can be revealing in several areas:

4.5.1. Moisture sensitivity

when an element such as a wall is dry it will conduct less heat than a wall that is damp, as the moisture entering the material (which is a good conductor of heat) takes the place of air (a poor conductor of heat). (Stuckes, et al 1986) Thus as the element contains more moisture the U value will increase. As some areas such as UK are predicted to have increased precipitation in the long term it is suggested that this will have an effect on the U values of heritage buildings which have a porous structure and as such the energy performance of these buildings will deteriorate over time, aside from increased precipitation, defects such as penetrating damp from leaks, and rising damp may also significantly affect the U value of a wall (Smith 2013).

4.5.2. Changes to construction

As a building element can change over time due to climate change, i.e. its thickness or make up, then so will its thermal conductivity. An example of this maybe the deterioration/spalling of masonry walls, this will ultimately leave the wall with a thinner cross section, and thus a higher conductivity and U value. This process may take a long time occur but frequent U value measurement or even better monitoring over a long period of time will make some of these changes visible, and also allow possible decrease in the energy performance of the building to be explored.

4.5.3. Improvements or changes

Improvements or changes to the fabric of a heritage building may also be measured using this method to verify and examine the changes in the thermal performance of the examined element, for example the addition of wall insulation. This will also help to inform further decision making around works of a similar nature.

4.6. Weather Stations

Weather Stations were added to each site monitored by the project. This chosen weather station is a relatively cost effective version, due to limitations in the project budget. There is a debate to be had on the accuracy of the equipment and the effect that this would have. However the chosen units allowed for data to be streamed directly into the HBIM database as live data, and for the data to be recorded. Weather data is also largely dependent on the location of the equipment (Meng et al. 2015), this is true of all data points recorded. Sensitivity to the location can be seen when comparing the height at which wind speed is measured, north and south facing temperature sensors and obviously the orientation of solar radiation sensors. To allow for comparison of weather/building exposure then these attributes should remain the same in buildings which are to be compared. If this is not the case then this will cause significant errors, and arguably much more substantial ones than the accuracy of the equipment.

4.6.1. Rainfall

Rainfall was measured with a traditional tipping bucket type system, which has proved accurate in other field tests carried out by the research team, this simply outputs a pulse signal every time the small bucket in the device is filled with rain and tips over to empty. The sensors are very basic, and tend to receive only vertical rain, the disadvantage is that wind driven rain (i.e. rain that is affected by horizontal wind and thus does not fall vertically) can be omitted from the results. However this is believed not to

be a significant component of the total rainfall. To measure wind driven rain uses a specialist device that was beyond the budget restrictions of this project.

Rain data is a key requirement for measuring the degradation of buildings, with rainfall amounts set to change around the globe. Rain is well known to damage buildings in many ways, in particular if they are not correctly maintained. But also the level of moisture around a building can significantly effect items such as the conductivity of the materials, which will help researchers identify anticipated changes in the u values of the walls for instance.

4.6.2. Wind Speed

Wind speed in this project was measured using a cup anemometer which is simply three half hemispheres attached to a spindle, when this spindle rotates a voltage is generated and converted using a processor to a wind speed in meters per second (m/s). There are more sensitive sensors on the market but this type is used by many other researchers in similar areas of building research (Blocken & Carmeliet 2005) (Mirsadeghi et al. 2013). Wind speed is a highly dynamic measurement and is sensitive to the location in which the sensor is installed, local microclimates can have an effect on the averaged and gust speeds. The wind speed For this reason the weather stations were mounted in indicative areas for the building, i.e. at roof level away from any significant obstructions, this will help achieve a general figure for the building rather than a one for specific wall etc. (Johnston et al. 2012). As mentioned earlier, wind can have many different effects on a building, so it is vital to be able for researchers to monitor this in the long term, to validate this prediction and also allow for mitigating strategies to be out in place.

4.6.3. Wind Direction

Wind direction coupled with wind speed is a valuable data point for monitoring building, after all prevailing and dominant winds can makes significant changes to the weathering of a building over time, in terms of degradation and also amount of wetting and drying of a buildings surface, which can lead to spalling etc. The measurements were taken using a simple vane system which measures the angle at which the wind arrives and converts this to either a degree or compass point field.

4.6.4. Air Tempertaure

Air tempertaure was measured as part of the main weather station unit, mounted at high level. This data point helps to investigate a lot issues such as freeze thaw cycles, long term changes in climate and also is the largest driver of thermal comfort and energy performance as it drives the need for heating and cooling in the studied buildings.

4.6.5. Relative Humidity

Relative humidity (RH) was recorded for the project, this is expressed as a percentage figure and a higher figure means more water vapour is present in the air water mix and thus is more humid. This figure can help diagnose issues in and around buildings, but in this case was used only outdoors, where it can be seen as a good indicator or precipitation events, and also the ambient RH can have an effect on the properties of many construction materials including stone and timber, prevalent in many heritage buildings.

4.6.6. Solar Radiation

Solar radiation was measured using a global radiation sensor (non-directional) this allows for solar radiation to be quantified, this can be useful for thermal modelling, an extra data set for the u value measurement and also measurement of the solar irradiance on the structure. Higher levels of solar radiation have been shown to add additional thermal stress to facades and also will affect the levels of deterioration by organisms such as lichens in a process known as biodeterioration (Sabbioni et al. 2010)

5. Barriers of Monitoring Climate Change in Heritage Buildings

There are many variables that are to be considered when examining climate change effect in heritage stock. We must consider not only the external or climatic conditions, but also the internal effects of these changes, the changes to the buildings themselves, and of course the effects on the users of these buildings.

Aim of this section:

1. To provide an outline of the technological challenges in this project
2. Identify, where possible, mitigation strategies of how these challenges were dealt with
3. Some ongoing work that is required to make this process a more efficient and valuable one.

5.1. Barriers in Egypt

Meeting the diverse information needed for decision making while seeking to understand and address climate change impacts on built environment is a formidable challenge. Many obstacles and barriers might get into the way of collecting and monitoring such on built environment in general and especially in heritage buildings within developing countries.

Monitoring climate change within heritage buildings requires several processes and steps that have to be taken within certain

5.1.1. Barriers of determining the required data and the relevant sensing and monitoring equipments

- 1) Lack of trained experts that have examines such information within heritage context.
- 2) Lack of national and in-house equipment required for sensing and monitoring climate change impacts on buildings.
- 3) The lack of knowledge about the relevant sensors and equipment within international context and the relevant producers and companies.
- 4) The difference between climate change impacts within different geographical zones due to different climate and different type of building types and materials within different could provide a conflict during consulting international experts in such field.

Such barriers have been overcome during mutual workshops and meetings between partner researchers from both Egypt and UK countries as the difference between climatic impacts between cold and arid climate, in addition to the type of heritage buildings under observation and the building materials. Mutual experiences have been exchanged within the context of:

- Type of needed data.
- Climatic qualities of different zones and countries.

- Cultural behaviors towards climate control within buildings (heating, cooling, ventilation...Etc).
- The relevant type of sensors needed for data collection
- The relevant producers and companies for required sensors.

5.1.2. Barriers of purchasing and receiving the equipment:

- Accuracy barrier in receiving sensors; receiving wrong devices according to online purchasing that might cause conflict while ordering.
- Regulation barriers; receiving equipments and sensors through international provider requires a lot of effort, time in addition to long process within Egypt which comprises in:
 1. Shipping and delivery of equipment could take long time as they should be received by the customs, then the main receiver should obtain certain release documents from different authorities.
 2. Government authorities' clearance:
 - a. The main approval was required from the National Telecom Regulatory Authority (NTRA) to clarify the purposes and the use of the sensor devices.
 - b. Other approvals are requested from other Egyptian authorities
 - c. Depending on the type of sensors which might take up to 6 month time.
 3. Extra costs acquired due to storing the devices in customs until receiving clearance approval from governmental authorities acquire extra charges that have to be paid from the project budget with no previous budget line.

5.1.3. Barriers concerning the Case Studies

The choice of a certain case study should consider certain situation that might delay the progress of the project as for Heritage buildings in Egypt could be used by governmental authorities for public use or by individuals such cases have to be dealt with according to each situation.

5.1.3.1. Case of Public-Use Buildings

Several barriers were faced with the case of adopting public-use buildings as case studies and they are as follows:

- The barriers of installing the sensors and devices in public use buildings require obtaining approvals from the relevant authority this needs extra time to be added to the time line of the project.
- Installing small devices and sensors in public use buildings should have a responsible person to be in charge of the sensors and that could not be found in public buildings
- Obtaining the original drawings for the public buildings could be an obstacle if the drawings are not available or they are not in their original conditions.
- Documenting, Surveying or photographing public use buildings might be not allowed in some cases, in addition it might require obtaining an approval from relative authorities.

5.1.3.2. Case of Private-Use Buildings

Several barriers were faced with the case of adopting private-use buildings as case studies and they are as follows:

- Private use buildings could have different obstacles due to the privacy of its occupants and their rejection of having sensors and monitoring devices within their daily life.
- Problems of documentation, surveying and photographing the building due to required permissions of their occupants.

5.1.4. Barriers of Installation and technological problems

The chosen sensors may not be all used and installed due to the differences in power meters in Egypt rather than the UK meters, in addition to the variation of case studies. The Optical Pulse Sensors were not installed as they are supposed to be connected to the electric meter and monitor optical pulses. However, electric meters in both case studies are old and don't function optically. Therefore, we were not able to install them. In addition, range extenders were not needed as they were meant to extend the range of connectivity between sensors and the monitoring unit and both current case studies are small in area. The installation fittings were not proper as some time the sensors fall of the wall.

The data capturing process is carried out through several websites. First one is the live website for the sensors created by the company itself through which we access and obtain live data. Second, is through the project's live data website which has been created by UK project partners and all of case studies is represented in this website. It also enables us to create graphs and analyze the data captured. Failure in data capturing existed due to the failure of internet that might be caused due to several power cuts that causes internet failure and unplugging the sensors accidentally.

5.2. Barriers in UK

5.2.1. Technological Barriers

The following section provides a brief outline of the technological processes that were used as part of this project.

5.2.1.1. Remote Environment Sensing

The buildings to be examined have a remote sensing package installed in them, this provides data on the following variables **inside** the building:

- Air temperature
- Relative humidity
- CO2 levels
- Volatile organic compound levels
- Lighting levels
- Energy consumption

This remote sensing package is a wireless arrangement that uses a ZigBee protocol to communicate wirelessly from each sensor back to a main data hub, this in turn passes the data through to an online platform where the data can be viewed analysed.

Whilst this may seem straightforward, wireless sensing is well known to be difficult to work with, especially in the dynamic environment of an occupied building. Swan et al carried out a recent study to determine some of the issues found by UK practitioners found in the field of Building Performance

Evaluation, which is the area that this project is working within. One of the main findings from this research was that equipment used for monitoring was problematic, in many areas: It is expensive when compared to other industries carrying out similar work, such as engineering, the equipment generally has unacceptable battery life, this is coupled with another problem that is often found in that the communications between the devices is frequently lost resulting in missing data, and unplanned visits to site to reset sensors (Swan et al. 2015). These problems were found by researchers on this project also. Many visits were made by the research teams to carry out maintenance on sensors, and whilst this was acceptable in the office property, the residential nature of the other properties makes this less acceptable.

Another aspect of providing wireless sensing to heritage buildings, is that of the fabric of the building itself, this poses two challenges, firstly the fitting/fixing of the sensors, which may damage the fabric of the building especially when being removed, and also the fact that some of the many of the heritage stock found in the UK, can have very dense masonry walls, not only externally but also internally which acts a blocker to wireless signals. So care has to be taken to place these sensors in locations which will not only minimise damage to the buildings, but also consider signal blocking.

Once the sensor data arrives at the datahub, another barrier is presented; the hub must be connected to the internet to allow the researchers to view the data. This requires a reliable and reasonably fast connection to the internet, this has to be secure and unhindered access. This was less of an issue with the domestic properties as, with the occupant's permission, the datahub was connected to the home broadband equipment. However where this was not possible, a portable 4g router was used to allow broadband connection to be made.

The measurement of energy consumption is a complicated topic, especially when dealing with such a wide range of properties as this project did. We collected gas and electric data for the properties in the UK. This tasks requires the sensor equipment to interface with the incoming utilities. This can be done in a number of ways. The project only require the basic energy inputs for the building.

5.2.1.2. Gas consumption measurement

Gas consumption measurement can be notoriously difficult to monitor and many researchers simply do not try and measure it (Swan et al. 2015) this is due to the large variety of meters that can be found. There is no "one size fits all" solution, as such many different devices exist or may different types of meter. These devices, have to meet several standards in the UK to make them safe to use (Technology Strategy Board 2011) (Tuffen et al. 2016):

- Appropriate CE / EMC Directive compliance
- Instruments Directive - 2004/22/EC as appropriate
- Be compliant with ATEX Directive 94/9/EC - this concerns safety where gas is present

The devices chosen by the team were fully compliant with the above requirements: an interface which measures the rotation of the digits on the front of the meter was used. This counts the revolutions made by these digits and passes this signal to the datahub. This is shown in Figure 17.



Figure 18 Gas meter reading equipment

5.2.1.3. Electricity Consumption

Electricity Consumption is slightly easier to measure as several possible routes can be taken; many electric meters have an LED which flashes in a rate proportional to the electricity being consumed, a sensor can be placed over this LED which allows the consumption to be read and sent to the datahub, this is the type used in this project, and is shown in Figure 18. Another method is to use a current transformer (CT) clamp to measure the current flowing through the mains incoming cable this simply clips round the live feed coming into the building. This should be carried out by a competent person, and errors can occur when the devices are incorrectly fitted (Tuffen et al. 2016)



Figure 19 Main incoming electricity meter monitored with an optical metering device.

5.2.1.4. Weather Station Data

The buildings were fitted with a weather station collecting data on the following variables:

- Wind speed and direction

- Rain
- Solar Radiation
- Temperature
- Relative Humidity
- Air pressure

As discussed before (p. 37-39), the process of collected weather data is highly sensitive to local microclimates around buildings and the topography of the surroundings, for this reason care needs to be taken to position this device in representative location to the buildings being observed. This was generally possible in most places. But this may not be the case for all heritage buildings, given issues such as planning/ and sensitivity of materials, for the fixing the device itself. The device is quite large and needs to be mounted on a pole, so arguably on an architecturally sensitive buildings these devices may not be suitable and could be located closely to minimise disruption to facades/rooflines etc.

Communications again was an issue. The weather stations communicate wirelessly via an RF signal to a central hub, which in turn connects to the internet where the data is posted to the HBIM server for viewing. A broadband connection is required for this, as the stations were located in remote locations at times, or in buildings with no accessible broadband a portable 4g router was used. This was also the same router as used for the environmental monitoring sensor package, so some cost savings were made.

5.2.1.5. Drone Scanning

Drone scanning was carried out for all of the building in the UK project. The aim was to generate a 3d model of the building in its current condition to allow for future comparisons to be made and also to provide input for 3d energy models and BIM models to be created. There are many issues with drone work in the UK, the legal issues will be covered elsewhere in this document. However the technological challenges were also numerous. Firstly the weather; the weather has to be fine and dry with little wind for the drone work to take place, this took some planning to make sure that we had the correct people present during a reasonable period of weather. Trees nearby to the building can be a significant issue for drone surveying, firstly they can restrict the flying area adjacent to the building, thus restricting low level flight around the building, also as the drone surveys are largely based around visual imaging, the trees can block the view of the buildings, leading to gaps in the reconstructed models. A mitigating strategy (although not possible due to project restraints) would be to carry out the work during the winter period when the leaves had fallen from the trees which can help visibility.

5.2.1.6. Laser Scanning

Laser scanning has become much more accessible in the last several years, with costs lowering and equipment getting more and more compact whilst still delivering accurate data for use in heritage work such as this project (Historic England 2011). However laser scanning at its simplest level delivers only 3d co-ordinates of a buildings surface, from here significant interpretation and data analysis is what makes the data so useful (Remondino 2011). Whilst some laser scanning can also include photographs, the research team found these not be high enough resolution on the equipment available, so photos had to

be captured manually or using the high resolution camera on the drone equipment. Laser scanning can generate very accurate digital surface maps of facades which can be useful for monitoring change in buildings (p. 33-34). However with the equipment available for this project this was limited to ground based measurements so roof features and other items only visible from higher levels were not included in the scan areas. There are now many mitigating strategies to deal with this issue. The researchers generated point cloud using traditional point cloud scanning, but were able to merge the data from the 3d models generated from the drone images to provide a dataset that also included the roofs this process was carried out using the software Contextcapture.

5.2.1.7. Air-Pressure testing

Air Pressure Testing is a well-accepted and developed procedure, as such other than timetabling the contractors no significant barriers were found.

5.2.1.8. U-Value Testing

This is a technique generally only used by building physics experts and academics in the field. The process involves attaching a series of sensors to the building fabric for a period of around 2 weeks. The equipment is costly, bulky and extremely sensitive (Fitton 2013). In many cases the technology and the standards that must be adhered to make this test impractical to carry out; the environmental conditions must be quite prescribed, in essence measurements must be carried out during the winter months, or late autumn/early spring. The internal temperature in the measured area must also be kept constantly elevated. Currently the equipment does not allow for remote sensing and is not battery powered so this means that the data must be collected manually and constantly observed for power outages etc. (Swan et al. 2015).

U-value measurement also has difficulties in the data analysis process, for a test measurement to be deemed a success the data must pass a series of “tests” for statistical validity, this can be quite involved and requires access to the data and current conditions, so ideally this needs to be done before the test rig is taken off the wall (ISO 2014).

5.2.1.9. Thermography

Thermal imaging work has some of the same limitations as the testing of U values, in that precise conditions have to exist for an accurate assessment to be made. Wind is expected to be at a minimum, no recent rainfall, the test should be carried out when no solar radiation has been present on the building for several hours (at night or dawn) and a temperature difference between inside and outside the building of $>10\text{ }^{\circ}\text{C}$ (which essentially limits the measurement to the same seasonal period as the U value test) (Balaras & Argiriou 2002)(BSI 1999). Without all of these safeguards in place, it is very difficult to make any significant/scientific observations of the building. It is worthy of note that a thermographic survey is a requirement of the U value testing, so many researchers choose to combine these tasks, also the airtightness test can also set up a certain condition where cold air from outside (depending on season) is drawn into the building through door frames and windows etc. These air leaks may be well observed using a thermal camera, so these tasks could also be coupled.

5.2.2. Other Barriers

5.2.2.1. Security

It is important to consider the privacy and security of all data collected in these types of projects. Datasets such as these can be a rich source of data, which can be misused such as examining electricity usage patterns to find when the building is empty. Other risks include the loss of data. It is for this reason that data privacy was a key part of this project, encrypted sensors were used and all data access was limited to users with a password.

5.2.2.2. Staff

The data collection methods highlighted above all have one thing in common, they require people to implement them. These people should be suitable trained and qualified and use methods that are standardised to allow for intercomparison of projects and to ensure that robust results are delivered. There is a problem generally in the UK of a lack of people to perform these tasks, especially U value measurement and censoring and monitoring installation. There is also a lack of guidance material and standardised methods for this type of work (Swan et al. 2015) (Pelsmakers et al. 2017). If the sensing and monitoring side of Heritage BIM is to develop then it is seen as essential that these skill sets are delivered.

6. Conclusion

The climate in the two countries which fall under this project (UK and Egypt) had very different climates, practically in every way possible. Yet one thing that unifies these two countries is the fact that over recent years (1961 and 1990) the climatic conditions have changed in every aspect; precipitation, rain, solar gain, temperature and wind. All of these conditions are set to carry on changing although in different levels and directions over the next 100 years according to current climate models. The literature has shown predictions that these changes could do significant damage to the stock of heritage buildings in both countries (Sabbioni et al. 2010). However these are only modelled, and often come with high levels of uncertainty. However with so much at stake this research must be taken into account and actions taken, the aspect that this paper puts forward is that continuous longitudinal studies are essential in this area, not only to map climate change and provide further inputs to help develop localised models, but also to understand that each building is not only unique in its makeup and performance but also that the environment that it sits in is also unique and constantly changing.

Where we can measure both of these things; the changing fabric of the building and the constantly changing climate then links between the two can be brought about and hopefully the risks to heritage buildings can be mitigated.

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