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Boston tidal barrier, UK: adapting to climate change and delivering social outcomes

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Climate-adaptation projects such as flood defence schemes must deliver wider societal benefits in the communities they protect to ensure long-term resilience and regeneration. This paper presents a case study of the £100 million Boston tidal barrier across the River Witham in Lincolnshire, UK, that now better protects over 13 000 homes from tidal flooding. The United Nations sustainable development goals provided a framework for monitoring and evaluating the wider benefits of the project and enabled its full societal benefits to be understood and communicated by all key project stakeholders. The primary barrier, completed in 2020, has delivered benefits against all 17 goals and is an example of how sustainability can be embedded into all aspects of a civil engineering project.

1. Introduction

Climate change is the long-term shift in average and acute extreme changes in weather patterns across the world, predominantly due to increased concentrations of greenhouse gases in the atmosphere (IPCC, 2019). This causes temperatures to rise and leads to long-term changes in climate, such as warmer temperatures, changes in precipitation and an increase in extreme weather events.

Climate change increases flood and erosion risk in coastal areas due to rising sea levels and increased storm surges, while inland areas see an increase in river and surface water flooding risk due to an increased intensity of rainfall. The impacts of flooding on people, communities, wildlife and the economy are vast – for example the winter floods in 2015−2016 cost the UK £1.6 billion (EA, 2018).

Responses to climate change fall into two categories

- climate mitigation: human intervention to reduce emissions of, or enhance the sinks of, greenhouse gases – for example by replacing fossil fuel with renewables (IPCC, 2019)
- climate adaptation: in human systems, the process of adjusting to the actual or expected climate and its effects to reduce harm or seek beneficial opportunities (IPCC, 2019).

Civil engineers have a significant role to play in both climate mitigation and adaptation. Infrastructure improvements are essential in both reducing greenhouse gas emissions and reducing climate risks to communities. Climate adaptation is achieved in many ways, including through construction of flood defences and securing transport, water, energy and communications systems against the impacts of extreme weather events.

Climate resilience is the capacity of a social, economic or environmental system to cope with a change in climate, whether a discrete event, a trend or a disturbance, while maintaining its essential function (IPCC, 2019). Improving climate resilience is complex and not something civil engineers can achieve alone. However, they have a role to play in building the capacity of the communities they work within by maximising social outcomes at all stages of a project's delivery.

Social outcomes can be understood as the broader economic, social and environmental effects of actions that make a conscious effort to ensure that their effects are positive. They should aim to add social value by contributing to the long-term well-being and resilience of individuals, communities and society (IED, 2020). Within the construction industry, this can be considered across several dimensions (Figure 1).

This paper focuses on the role of civil engineers in improving infrastructure and community resilience through climate-adaptation measures, and the importance of considering social outcomes in construction projects both to minimise climate risk and maximise climate resilience. The UK's Boston tidal barrier is a good example of how climate-adaptation projects can deliver wider social outcomes. This is not only 'the right thing to do' for communities, it also builds local social, economic and environmental capacity to improve the overall resilience of communities to climate shocks and stresses.

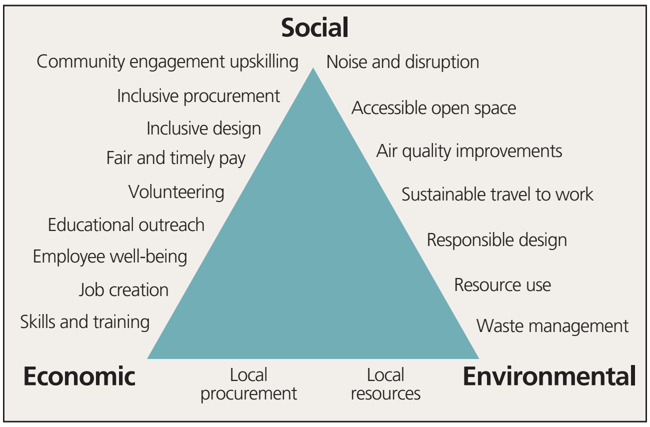

Figure 1. Social value dimensions within construction (Institute of Economic Development)

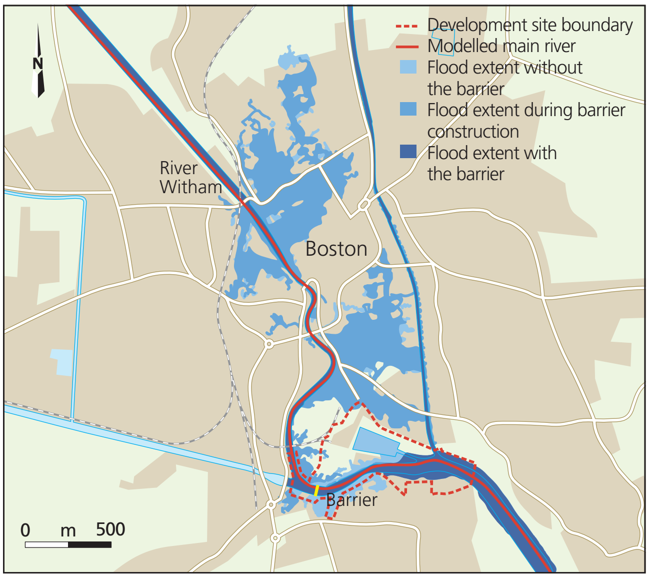

Figure 2. Plan of Boston showing tidal flood risk extents for a 1 in 300 year flood event before the barrier, during barrier construction and with the barrier in operation (Mott MacDonald)

2. Boston barrier scheme

Boston is a market town in Lincolnshire with an important maritime history, located on the edge of The Wash in the low-lying fens. The tidal River Witham presents a flood risk to the town, particularly during tidal surges. Boston is entirely situated in the floodplain and already relies significantly on tidal flood defences. In the past 200 years the town has experienced nine major instances of tidal flooding. The most recent tidal surge event in December 2013 flooded over 800 properties across 55 streets.

The nearby coast is projected to experience sea level rise of between 0.23 m and 0.29 m by 2050, and between 0.44 m and 0.77 m by 2100 due to climate change, based on the 50th percentile values for the lowest and highest greenhouse gas emission scenarios (Met Office, 2018). The current level of tidal flood protection in Boston is low, with a 2% probability of flooding in any one year. However, climate change induced sea level rise and an increase in storms will result in the standard of protection for the town diminishing without intervention. In January 2012, the Association of British Insurers (ABI) assessment placed it as top of its list of areas with homes at significant flood risk (ABI, 2012). Figure 2 shows the modelled tidal flood risk extents with the existing defences and with the new barrier.

Without intervention, the existing tidal flood defences had a high probability of being overtopped and breached. A breach would be followed by a rapid inundation of the low-lying land behind. By 2110, the consequences of failure in a ‘do nothing’ scenario without the scheme were predicted to result in permanent loss of over 17 000 residential and commercial properties due to regular tidal flooding, and an increased risk of loss of life from remaining properties at significant flood risk.

Alongside high physical flood risk, the town has low resilience to climate hazards. It was ranked as the 66th most deprived council area in England out of 326 local authorities in 2015, and has one of the lowest average weekly wages in England (DCLG, 2015). Following the 2013 flood event, Boston Borough Council commissioned a survey among those flooded, which identified that 419 of the 424 who replied had no contents insurance. St Botolph’s Church, community focal point and grade 1 listed property, took 3 years and cost nearly £1 million to repair following the December 2013 surge (Parish of Boston, 2018).

High flood risk and a lack of resilience to flooding means the town struggles to attract investment. Without a reduction in flood risk, the town’s deprivation issues would struggle to be addressed and new regeneration schemes would be unlikely.

The main objective of Boston’s barrier scheme was to reduce the risk of flooding for people and the built and natural environment in the town. The scheme now offers protection against an extreme tidal flood event with a 1 in 300 (0.33%) chance of happening in any one year over a 100 year time period, including allowance for climate change. The net present value benefits of the barrier were estimated to be £1116 million (October 2015 cost base).

The scheme was identified as a national priority project in the UK government’s 2014 autumn statement, forming part of a programme to reduce the risk of flooding to 300 000 homes by 2021 (GOV.UK, 2014). The project was 100% eligible for flood defence grant-in-aid and the scheme was approved by HM Treasury in October 2016.

The scheme is being carried out as a partnership between the Environment Agency (EA), Lincolnshire County Council, Boston Borough Council and Black Sluice Internal Drainage Board. A BAM Nuttall and Mott MacDonald joint venture was awarded the design-and-build contract through the EA’s water and environmental management framework and it began construction in 2017. The barrier became fully operational in December 2020 and the scheme will be completed in 2022.

Figure 3 shows an overview of the scheme. Its design flood level is +7.55 m above ordnance datum. It provides a combination of floodwalls and gates to create a continuous impermeable defence between the river and the town, preventing inundation from tidal surges.

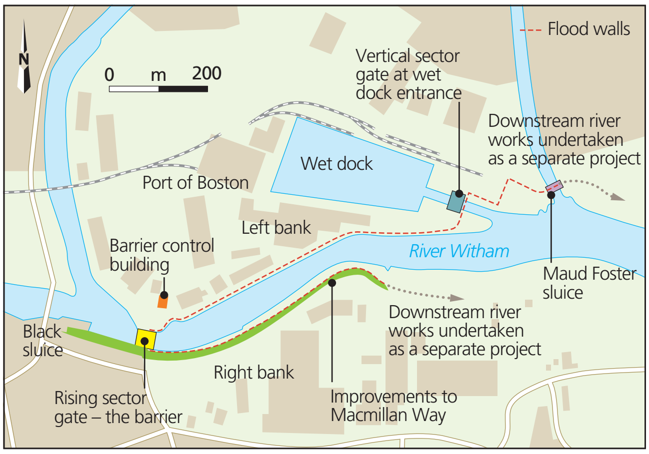

Figure 3. Site plan of the various elements of the Boston barrier scheme (Mott MacDonald)

The main components of the scheme are as follows.

- Rising sector gate – a 362 t, 26 m wide, 11 m high gate that will be raised during tidal surges by two 55 t hydraulic cylinders. The completed gate can be seen in Figure 4 and the building information model (BIM) render is shown in Figure 5.
- Barrier control building – provides control of operation and maintenance of the barrier.
- Wet dock entrance – an 18 m wide, 11.5 m high pair of vertical sector gates to complete flood wall protection around the port.
- Left bank works – an 830 m long, 2 m high flood wall; a 590 m long, 19 m deep anchored sheet-piled quay wall in the port; and three piled load-relief platforms for port crane operations during the wet dock closure period.
- Right bank works – a 525 m long, 19 m deep anchored sheet-piled flood defence wall and new landscaped embankment along the Macmillan Way to enhance the social and environmental impact of the project (Figure 6).

Collaborative working and digital delivery were central to procurement. The project's common data environment and BIM enabled the contractor to optimise integration of existing structures, temporary and permanent works, saving time, money and carbon dioxide emissions. Examples of design and construction innovations developed through this approach include the following.

- Integration of permanent and temporary works within the twin-wall cofferdam increased craneage capacity during construction, reducing the need for single-use temporary works structures. This enabled the gate to be driven into position by self-propelled modular transporters from a barge (Figure 7).
- Use of precast concrete elements to form the dish-shaped gate recess negated the need for a bespoke single-use 200 t steel shutter.
- Concrete mix for the barrier structure incorporated 70% ground-granulated blast-furnace slag, a by-product of the iron industry, as a cement replacement. This saved a total of 1250 t of carbon dioxide emissions across the 6000 m^3 of concrete required in the barrier structure.

Figure 4. The 362 t rising sector gate is 26 m wide, 11 m high and became operational at the end of 2020 (Environment Agency)

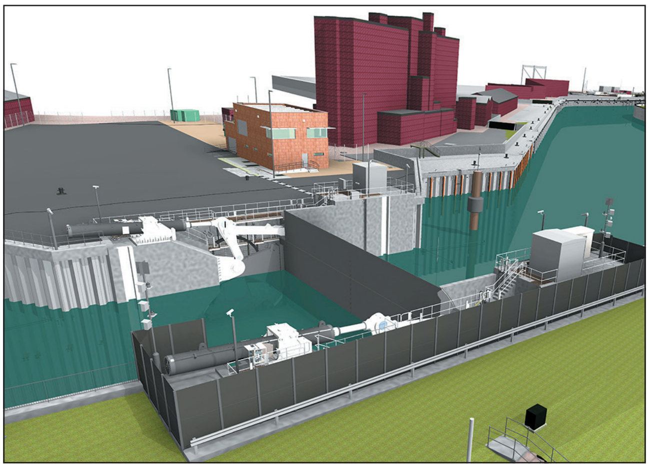

Figure 5. Building information model render of how the completed barrier and control building looks now (BAM Nuttall and Mott MacDonald joint venture)

Figure 6. Murals on the new right bank floodwall reflect the town's maritime history and were developed in consultation with the local community (BAM Nuttall and Mott MacDonald joint venture)

Figure 7. Integration of permanent and temporary works in the cofferdam enabled the gate to be driven into position from a barge using a self-propelled modular transporter (Environment Agency)

- Inverting the design concept of the barrier plant and control room to position all essential plant on the first floor achieved the required level of operational resilience against flooding without needing to waterproof the entire structure. This removed the requirement for piled foundations to provide resistance against uplift and enabled deletion of 70 piles. Key benefits were a significant reduction in buried obstruction risk, reduction of 360 t of embodied carbon dioxide and savings of £0.3 million.

A community hub was provided on site to allow direct access to the project team every week for community outreach projects and questions, a first for the EA (Figure 8). The community hub model was shared across the EA and resulted in the creation of the Mytholmroyd flood information centre after the 2015 Calderdale floods in West Yorkshire.

Figure 8. Community engagement session at the Boston barrier community hub (Environment Agency)

3. Social outcomes

There is no universally recognised process for quantifying the social outcomes of a major construction project such as the Boston barrier. The project team used the 17 United Nations sustainable development goals (SDGs) as a lens to analyse and measure the wider impacts of the project on society.

The EA is increasingly using the goals to create better solutions and embed social, economic and environmental considerations throughout decision making processes. The goals are incorporated into the EA's national flood and coastal erosion risk management strategy across the whole of England and are also set out in its 25 year environment plan.

The Boston project team developed a methodology based on the goals to assess the contribution of the project to each one, considering both direct and indirect impacts. The scheme was found to contribute positively to all 17 goals across 25 targets. Figure 9 shows the targets that the scheme supports and Table 1 provides evidence of the project outcomes against each goal target identified.

A summary of the methodology used is as follows.

- All direct project outcomes were collaboratively identified by key stakeholders, ensuring the scheme's impacts on all stakeholders were considered across the design, construction and operational stages of the scheme.
- For each direct project outcome identified, an assessment of its impact was undertaken against all goals.
- When a project outcome was identified as having a link to a specific goal, the outcome was assessed against each target within that goal, and links between direct outcomes and specific targets were captured.
- Next the team worked through all goals and targets, considering if any of the identified project outcomes had an indirect impact on that target. When indirect links were identified, this was also captured.
- Finally, the indirect and direct impact on each target was combined to provide a total contribution. A subjective scale of impact was determined by the team based on the evidence compiled, and these were used to determine the weightings shown in Figure 9.

Figure 9. Contribution of the scheme to each United Nations sustainable development goal target – the size of bar represents the scale of positive impact (Mott MacDonald)

Table 1. Contribution of the Boston barrier scheme to individual UN SDG targets

UN SDG target	SDG target description	Boston barrier scheme contribution
1.5	Build the resilience of the poor and reduce their exposure and vulnerability to climate-related events	Boston contains some of the most deprived wards in England based on the index of multiple deprivation. These parts of Boston suffer from considerable deprivation and poverty, with a low skilled workforce and one of the lowest average weekly wages in England (EA, 2020). The Boston barrier reduces the exposure of these communities to extreme climate-related tidal events.
2.4	Ensure sustainable food production systems… that strengthen capacity for adaptation to climate change and flooding	Food production and farming within Lincolnshire contribute £1 billion to the economy each year. Lincolnshire is the largest producer of wheat, cereals and potatoes in the UK. Boston is at the centre of this agricultural heartland as a centre of food processing, packaging and export – contributing significantly to the nation's food security. Flood protection of these assets increases security of food supply across the UK and provides employment opportunities within Boston.
3.8	Access to quality essential healthcare services	The scheme provides tidal flood protection to Pilgrim Hospital, the second largest hospital in Lincolnshire which provides major specialist treatment and 24 hour major accident and emergency services to the whole of south and south-east Lincolnshire. Pilgrim Hospital provides over 7000 jobs locally (NHS, 2020).
4.4	Increase the number of youth and adults who have relevant skills… for employment and decent jobs	The contractor provided apprenticeships to six young people, providing them with technical skills and employment opportunities. The contractor also has a scheme which provides return-to-work opportunities for people who have been out of work for several years. The Environment Agency engagement team worked with local schools and colleges to educate on flood risk and engineering.
5.1	End discrimination against all women	There was a good gender mix within the project delivery team; 41% of the design team were women, which was unusually high for the industry. The project was part of the 'women in construction' scheme.
6.3	Improve water quality by reducing pollution	There were numerous outfalls into the River Witham, including those associated with the sewerage network, wastewater treatment, flood risk and land drainage functions. Flood risk reduction limited the number of unplanned outfall events, reducing pollution into river and marine systems. Interceptors were provided at all surface water outfalls along the left bank to prevent accidental oil spills, and marine-safe hydraulic oil was used in the hydraulic cylinders controlling the rising sector gate.
6.6	Protect and restore water-related ecosystems, including wetlands and rivers	Tidal flood protection prevented permanent change to or impacts on freshwater ecological features due to regular sea water intrusion. Salt marsh restoration was provided where the scheme's construction impacted on wetland habitats.
7.2	Increase substantially the share of renewable energy	A total of 32 photovoltaic panels were installed on the roof of the barrier control building, providing a 9.6 kW renewable power supply along with an air-source heat pump. Combined these provide an annual carbon dioxide offset of 6.1 tonnes carbon dioxide equivalent.
8.3	Support productive activities, decent job creation, entrepreneurship	Over £6 million was spent on construction materials and services within 80 km of the site, and the value of money spent within the local economy was a key performance indicator for the contractor. The project provides flood protection to 582 local businesses and it is anticipated that reduced flood risk will encourage local investment and the development of new employment opportunities within Boston.
8.5	Achieve full and productive employment and decent work for all	
8.6	Reduce the proportion of youth not in employment, education or training	See evidence for target 4.4.
9.1	Develop quality, reliable, sustainable and resilient infrastructure	The project provides significant tidal flood protection to local infrastructure assets, including the A16 trunk road which is also a vital emergency evacuation route; the railway line between Boston and Skegness; the Port of Boston; the local electricity sub-station; and emergency services such as Pilgrim Hospital, schools, fire service and police station.
10.1	Achieve and sustain income growth of the bottom 40% of the population.	See evidence for target 1.5.
10.2	Empower and promote the social, economic and political inclusion of all	Community engagement campaigns were inclusive. Boston has a high proportion of residents born in the EU or accession countries at 17.1% (ONS, 2020). Campaigns were multilingual across seven languages and run on several platforms. Translators were available at public drop-ins and sessions were run from 12.00–19.00 hours to allow access for those with differing working patterns. Sessions also included hearing aid loops during the public inquiry process, and plain text versions of the project newsletter were sent to the visually impaired.

Table 1. Contribution of the Boston barrier scheme to individual UN SDG targets (continued on next page)

Table 1. Continued

UN SDG target	SDG target description	Boston barrier scheme contribution
11.1	Ensure access for all to adequate, safe and affordable housing	After the 2013 Boston flood, 114 households approached being homeless or needing housing advice. The Boston barrier scheme protects 14 265 properties from tidal flooding, increasing access to safe and affordable housing. Reduced risk and potential increased insurance coverage can reduce the direct economic losses caused by tidal flooding for all.
11.5	Reduce the number of people affected and substantially decrease the direct economic losses caused by disasters	
11.7	Provide universal access to safe, inclusive and accessible green spaces	Improvement was made to the Macmillan Way, a long-distance walking trail, along the right bank of the scheme. The path is now wheelchair accessible and inclusive to all. The project team held stakeholder workshops to improve the footpath's new flood-walls which now include motifs depicting maritime imagery in keeping with Boston's seafaring history (Figure 5). The project also supported Boston Borough Council's local public landscape projects to create a sculpture trail from reclaimed buoys. It worked with local woodcarvers in creating sculptures along Macmillan Way using reclaimed wood dredged during the scheme.
12.2	Achieve the sustainable management and efficient use of natural resources	The 2013 flood generated over 300 t of waste from flooded homes. Preventing tidal flooding stops the cycle of damage, disposal and rebuilding of the town. The contractor has reduced waste and recycled resources where possible. Examples included (a) reuse of dredged material as backfill and capping at a local landfill site, avoiding the need for 30 000 lorry movements (b) collaboration with concrete supplier to reduce the cement content of the actual supplied mix while still ensuring it met minimum strength requirements – this saved 120 t of cementitious material across the 6000 m^3 of the primary barrier structure (c) maximising the use of prefabricated elements in construction, such as the concrete gate recesses and pre-fixed rebar cages – this reduced waste materials produced on site and temporary formwork requirements.
12.5	Reduce waste generation through prevention, reduction, recycling and reuse	
13.1	Strengthen resilience and capacity to climate-related hazards	Climate change causes rising sea levels and increased risk of extreme weather events. These both increase the risk of tidal surges at Boston. The barrier prevents surges inundating the town and increases local resilience to these hazards.
13.3	Improve education and awareness raising… on climate change	Public engagement campaigns included awareness raising of climate hazards through the project. It was a project objective to share knowledge with technical experts and the local community. Outcomes include (a) holding 'lunch and learn' webinars for the ICE (b) educational outreach sessions and providing learning materials to local schools, colleges and scout groups (c) holding talks for local interest groups and societies (see Figure 8).
14.1	Prevent and significantly reduce marine pollution of all kinds	See evidence for target 6.3.
15.5	Reduce the degradation of natural habitats, halt the loss of biodiversity and protect threatened species	Tidal flood protection prevents permanent change to or impacts on freshwater ecological features and habitats due to regular sea water intrusion. The project team introduced a terrestrial plant population of nationally rare Boston horsetail along the Macmillan Way.
16.7	Ensure inclusive, participatory and representative decision making at all levels	Extensive consultation took place with the local community and river users to avoid any unintended negative impacts. Collaborating with the Port of Boston, the project team used HR Wallingford's UK ship simulation centre to create a virtual navigation simulation, see Figure 10. This was the first time in the centre's history when the system had been adapted to include leisure craft and it enabled all river users to pilot their vessels virtually. This helped the whole river community to understand the future navigation changes and allowed collaborative discussions between stakeholders, which directly influenced the navigation management plan.
17.16	Enhance multi-stakeholder partnerships that share knowledge, expertise, technology and financial resources, to support the achievement of the SDGs	

ICE, Institution of Civil Engineers; SDG, sustainable development goal.

To make sense of such a significant carbon dioxide investment, the scheme needs to be considered in the context of wider societal benefits as well as the emissions cost of 'do nothing', such as multiple post-flood rebuilds

4. Discussion

The lessons learnt through the Boston barrier case study can be applied by civil engineers to a range of climate-adaptation schemes regardless of scale or location. The most significant lessons learnt are discussed further below.

4.1 Applicability of SDGs to civil engineering

The SDGs were not developed specifically for the construction context and therefore it can be hard to trace direct links between some of the targets to civil engineering project outcomes. However, the process of collaboratively working through the goals as a project team was beneficial and offered a new perspective on project outcomes and their connections that may not have been recognised otherwise.

A key benefit of the goals is that they provide a universal language and framework for demonstrating societal outcomes across sector and discipline boundaries. The framework provides improved communication and collaboration opportunities between multiple stakeholder organisations, and enables the benefit maximisation of climate-adaptation schemes to be approached and understood, well beyond just the civil engineering profession.

The Boston barrier scheme concept was first developed in 2008, several years before the SDGs were established in 2015. Most, if not all, of the project outcomes discussed in Section 3 were established well before the goals, and it would be an exaggeration to claim that the goals influenced decision making at all stages of the scheme. Good design, a desire to do the right thing and the need to maximise flood protection benefits while driving down costs resulted in selection of the final project solution. However, had the goals been available at project inception and optioneering stages, it is likely further benefits could have been provided through the project.

It is recommended that the goals should be mapped to climate-adaptation project aims and outcomes as soon as possible in the optioneering and initial design stages. At early stages there is greatest opportunity to influence the overall project scope and therefore maximise societal benefits.

The EA has been working with London South Bank University and the Thames Tideway sewer project on measuring infrastructure SDG impacts. This will help identify when joint strategic partnerships are aligned to deliver cost-effective outcomes with the SDGs, thereby improving infrastructure and ensuring that cross-government funding is invested in priority target areas.

4.2 Benefits of digital delivery approaches

The primary driver for digital delivery approaches on the Boston barrier scheme was to reduce costs and increase efficiencies by reducing waste, improving build clarity and ensuring information was managed and stored correctly. The efficiencies gained through these approaches in turn reduced the material requirements and waste produced during construction, which reduced the environmental impacts of the scheme.

The three-dimensional BIM has also been valuable as a communication tool, both within the project team and externally for use in stakeholder engagement and communications. The imagery, graphics and videos developed using the model were used throughout the planning process, public consultations, community outreach sessions, media updates and river navigation simulations undertaken for river users (Figure 10).

The benefits provided by BIM within the public communications and external engagement of the scheme were significant and should be considered at the beginning of every project when determining the cost–benefit of implementing similar digital approaches.

4.3 Feasible scope of emissions reduction

There has been much discussion of climate adaptation and resilience in this case study; however, the importance of reducing greenhouse gas emissions cannot be understated. While embodied carbon dioxide has been minimised wherever possible, building a zero carbon dioxide flood defence on the scale of the Boston barrier is currently impossible.

While there are few operational emissions, the construction required significant volumes of concrete and steel to meet the necessary flood defence level over the 100 years design life. Some of the innovations described in Section 2 led to reductions in emissions relative to the baseline scheme concept, but the project was nonetheless heavy in embodied carbon dioxide.

To make sense of such a significant carbon dioxide investment, the scheme needs to be considered in the context of the wider

Figure 10. The project building information model was also used for river navigation simulations at HR Wallingford (Environment Agency)

societal benefits brought about as well as the emissions cost of 'do nothing', for example multiple post-flood rebuilds.

4.4 Importance of considering the local context

Considering and incorporating the local context of communities into project decision making is critical to ensuring sustainable and socially inclusive outcomes. Boston has a unique cultural, historical and economic context, and providing social value was only possible when the local community and context were well understood.

For the barrier this meant recognition of the following: historical context of the town's ancient maritime port; local income inequality; maximising the benefits of the Macmillan Way; establishing the nationally rare plant species, the Boston horsetail, which has historical links to the town; and including the town's significant eastern European community through multilingual community engagement campaigns.

4.5 Climate resilience is more than physical protection

Tidal surge protection is a critical part of protecting Boston from rising sea levels and reducing climate hazard exposure. It must also be remembered that the town is still exposed to other climate hazards such as fluvial and surface water flooding, heat waves, droughts and extreme storm events.

Climate resilience is more than physically defending communities from extreme weather events; it also requires the strengthening of social, economic and environmental systems within communities. It is anticipated that the wider societal benefits of the Boston barrier will increase the overall capacity of the community, therefore reducing the impact and devastation caused by climate impacts and natural hazards in the future.

Climate-adaptation schemes must be inherently sustainable to achieve true improvements to local climate resilience.

5. Conclusions

The Boston barrier scheme has delivered increased climate resilience to Boston by providing improved protection from tidal flooding. It has also been demonstrated that its construction, as a climate-adaptation project, has provided wider social outcomes.

Social outcomes need to be incorporated when civil engineers plan, implement, construct, operate, maintain and decommission infrastructure projects. It is recommended that the United Nations SDGs should be mapped to climate-adaptation projects at the optioneering and initial design stages. This will enable the most effective and efficient benefits to be realised, not only by the client and delivery teams but by all community stakeholders.

Climate change is the greatest challenge to overcome in the twenty-first century. It will require rapid assessment and investment in climate-adaptation projects across all infrastructure sectors in the coming years. But true climate resilience is more than defending communities from extreme weather events: it requires the strengthening of social, economic and environmental capacity within communities. Sustainability is inherently part of climate resilience. Climate-adaptation projects can and should deliver wider societal benefits in the communities in which schemes are required.

Stakeholders working together in strong partnerships can enhance what civil engineers deliver within society. This will ensure that future generations inherit assets that are adapted to a changing climate as well as building the capacity of communities to improve their resilience to climate hazards in all forms.

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References

ABI (Association of British Insurers) (2012) *ABI Warns of Increased Flood Risks in England and Wales*. See https://www.insurancejournal.com/news/international/2012/02/01/233659.htm (accessed 19/01/2020).

DCLG (Department for Communities and Local Government) (2015) *English Indices of Deprivation 2015*. See https://www.gov.uk/government/statistics/english-indices-of-deprivation-2015 (accessed 19/11/2020).

EA (Environment Agency) (2018) *Estimating the Economic Costs of the 2015 to 2016 Winter Floods*. See https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/672087/Estimating_the_economic_costs_of_the_winter_floods_2015_to_2016.pdf (accessed 19/11/2020).

EA (2020) *The Boston Barrier Order – Statement of Case of the Environment Agency*. See https://consult.environment-agency.gov.uk/engagement/bostonbarriertwao/results/statement-of-case-of-the-environment-agency.pdf (accessed 19/11/2020).

GOV.UK (2014) £146 million to be spent on new flood defences. See https://www.gov.uk/government/news/146-million-to-be-spent-on-new-flood-defences (accessed 19/11/2020).

IED (Institute of Economic Development) (2020) *From the Ground Up – Improving the Delivery of Social Value in Construction*. See https://ied.co.uk/images/uploads/WST458_Social_Value_Report_v11.pdf (accessed 13/01/2021).

IPCC (Intergovernmental Panel on Climate Change) (2019) Annex I: glossary (Weyer NM (ed.)). In *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* (Pörtner H-O, Roberts DC, Masson-Delmotte V, *et al.* (eds)). See https://www.ipcc.ch/site/assets/uploads/sites/3/2019/11/12_SROCC_AnnexI-Glossary_FINAL.pdf (accessed 19/01/2021).

Met Office (2018) *UKCP18 Marine Projections*, accessed through UK Climate Projections User Interface. See https://ukclimateprojections-ui.metoffice.gov.uk/ui/home (accessed 19/10/2019).

NHS (National Health Service) (2020) *Pilgrim Hospital Boston*. See https://www.ulh.nhs.uk/hospitals/pilgrim-hospital-boston/ (accessed 19/11/2020).

ONS (Office for National Statistics) (2020) *2011 Census: Aggregate Data* [data collection]. UK Data Service. SN: 7427. See http://doi.org/10.5257/census/aggregate-2011-2 (accessed 19/11/2020).

Parish of Boston (2018) *St Botolph's 'A Passion for People' Project Awarded £1.17m National Lottery Grant*. See https://parish-of-boston.org.uk/2018/08/st-botolphs-a-passion-for-people-project-awarded-1-17m-national-lottery-grant/ (accessed 18/11/2020).