Integrating nature-based solutions and the conservation of urban built heritage: Challenges, opportunities, and prospects

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Abstract

Nature-based solutions (NbS) offer opportunities to incorporate green elements into cultural heritage conservation and management practice in cities and unlock associated co-benefits. However, concern about potential negative impacts of nature on built heritage (i.e., biodeterioration of heritage materials, loss of heritage values, and complicating practical heritage conservation and management) can act as a barrier to the uptake of NbS in some locations. We propose that NbS could be adapted, developed, and applied to address specific heritage conservation challenges as well as contribute to wider social benefits. In turn, urban built heritage can provide a valuable and largely underexplored space for NbS activities. Focussing on ten key benefits of NbS in cities (improving health, sequestering carbon, enhancing biodiversity, providing acoustic comfort, reducing the urban heat island,

enhancing sustainable water management, facilitating urban agriculture, improving air quality, contributing to economic vitality through jobs and investment, and enhancing social cohesion), we illustrate how built heritage can both benefit from NbS and contribute to their wider success. We show how built heritage can benefit through reducing or mitigating the deterioration of heritage materials, improving the visitor experience, enhancing values, and stimulating investment. At the same time, built heritage conservation can support the delivery and success of NbS in cities by offering additional locations to implement and connect NbS schemes, providing inspiration for closer relationships between nature and society, and enriching NbS benefits by adding a cultural element. We conclude that flexibility is needed to link built heritage and NbS, yet the opportunities are great. Cultural and natural heritage are vital components of resilient and sustainable urban communities, fostering shared values by connecting people with the past and with nature. Better integrating built heritage into the wider NbS paradigm shows great promise for strengthening and broadening these linkages.

Keywords: heritage conservation; NbS; historic buildings; urban heritage; green infrastructure; urban nature

1. Introduction

The nature-based solutions (NbS) concept has emerged following recognition of the positive (and negative) linkages between people and nature within the nature conservation and development sectors (Cohen-Shacham, 2016; Nesshöver et al., 2017). In cities, the focus is on incorporating natural elements in new development designs—increasingly through planning policy—under the umbrella of green infrastructure (GI) to maximise social, environmental, and economic benefits (Tzoulas et al., 2007; Pauleit et al., 2019). More broadly, GI and other forms of NbS can help address major societal challenges including

52 climate change, disaster risks, and economic and social development and inequality (Gaffin et
53 al., 2012; Cohen-Shacham, 2016; van der Jagt et al., 2019; IUCN, 2020). In the heritage
54 sector, the leading international authority on cultural heritage (the United Nations
55 Educational, Scientific and Cultural Organization, UNESCO) also recognises that the NbS
56 concept offers opportunities for more sustainable solutions to heritage conservation, although
57 discussion has so far largely focussed on water management and the mitigation of natural
58 disasters such as floods (UN-WWAP, 2018). Despite some progress, there has been limited
59 consideration of heritage conservation principles and heritage values in urban NbS
60 discussions; the ways in which nature can be used to help conserve and enhance built heritage
61 remain largely unarticulated and underexplored, particularly for urban heritage buildings,
62 monuments, and sites.
63
64 At the same time, opportunities for built heritage conservation to contribute to the wider
65 delivery of NbS in cities are rarely discussed. For example, in their assessment of the
66 linkages between NbS, ecosystem services, and urban challenges, Babí Almenar et al. (2021)
67 show that whilst the built environment continues to be an important focus of research, very
68 few studies have explored the preservation of cultural heritage in these contexts. Indeed, their
69 analysis implies that the theoretical and practical linkages between cultural values and urban
70 challenges remain vastly underdeveloped. Here, we aim to address these gaps by providing
71 some initial ideas about the potential links between delivering NbS benefits and the
72 conservation of built heritage in cities. Throughout, we use ‘built heritage’ to refer both to
73 physical assets (buildings, walls, monuments, historic gardens, etc.) and the management
74 principles and practices employed to conserve them and their values. Although much of our
75 discussion is framed in a context of ‘historic’ (pre-20th century) built heritage, we
76 acknowledge that ‘modern’ heritage, such as 20th century industrial buildings and ruins,

77 warrant just as much consideration, especially where this forms a significant proportion of the
78 urban land area.
79
80 *1.1. Filling the gaps in our green cities*
81 Rather than protecting and enhancing 'natural' habitats and ecosystems (so-called 'type 1'
82 NbS), NbS in cities typically involve the design and use of built assets as new or novel
83 ecosystems ('type 3' NbS) alongside broader-scale interventions to maximise
84 multifunctionality and sustainability ('type 2' NbS) (Eggermont et al., 2015; Cohen-
85 Shacham, 2016). Whether through designing new GI or retrofitting existing assets with green
86 elements, focus has shifted towards delivering co-benefits and enhancing the connectivity of
87 the wider GI network (e.g., Rusche et al., 2019; Zhang et al., 2019). Given that built heritage
88 is a valuable and sometimes extensive component of the urban landscape, significant
89 opportunities as well as challenges exist for developing and implementing NbS in these
90 contexts. This is especially the case in historic cities where a significant proportion of the
91 land area may be occupied by sites designated as 'heritage'. As such, including built heritage
92 in the NbS agenda can help 'fill the grey gaps' in the urban landscape, avoid the potential trap
93 of a grey 'historic hole' in our cities, and contribute to the development of a more connected
94 and resilient GI network (Rusche et al., 2019; Parker and Simpson, 2020).
95
96 There are potential challenges, of course. Cities contain a patchwork of green, blue, and grey
97 assets, some old and some new, that are valued for a wide range of reasons by a diverse mix
98 of individuals and communities. Yet in most GI frameworks, 'buildings' (i.e., walls and
99 roofs) are typically discussed as a single category of infrastructure to be 'greened'. This fails
100 to capture the nuance and specific challenges of greening individual buildings (and other
101 types of built asset including boundary walls, ruins, and bridges) that are managed,

conserved, and valued primarily for heritage reasons. In these cases, the core concern is the conservation and enhancement of historical, evidential, aesthetic, and communal heritage values (Waterton and Smith, 2008; Stones, 2016). Whilst not always the case, it is important to recognise that such a focus on heritage conservation can be different from—and even contradictory to—the aims and priorities of managing and implementing urban NbS. This not only includes specific legislative and planning restrictions in the case of listed/protected buildings and sites but also the perceptions, received wisdom, and potentially conflicting opinions of heritage managers and heritage consumers. Given that the success of NbS must ultimately be measured against the specific challenges they seek to address (Cohen-Shacham et al., 2019), for urban built heritage, opportunities for using NbS in the conservation of heritage assets and values warrant further consideration.

1.2 Opportunities for integration

One way of strengthening the conservation of cultural and natural elements in cities is to focus on what links them. All heritage consists of natural and cultural elements, and whilst the balance between them varies hugely, there may be opportunities for mutual gain. Although there have undoubtedly been significant developments, such as the establishment of the Joint UNESCO-Secretariat of the Convention on Biological Diversity (SCBD) programme on 'Linking Biological and Cultural Diversity' (https://www.cbd.int/lbcd/, accessed April 2021), heritage research and conservation practice have tended to follow polarized cultural and natural strands. At one end of the spectrum, nature is seen as a threat to cultural heritage (i.e., buildings, objects, practices, and values), and at the other end, human culture is seen as a threat to natural diversity. Indeed, the potential 'natural' elements of heritage buildings and sites, ranging from microbes to trees, are rarely considered; whilst greening, ecological engineering, and urban biodiversity concepts are increasingly adopted in

modern urban planning, this kind of thinking has lagged behind in heritage studies where a 'nature is a threat' narrative still dominates. A fundamental challenge, of course, is that microbes, plants, and animals *can* pose very real and sometimes unacceptable threats to culturally valued buildings and heritage sites, especially when composed of potentially sensitive materials like historic stone. We cannot, therefore, expect efforts to embed NbS in cities—largely via greening interventions—to be universally applicable to heritage buildings and sites. Yet the 'sterile but stable' paradigm in built heritage conservation (Viles, 2012; Fig. 1) need not apply in all cases. There are opportunities to incorporate green elements into cultural heritage conservation and management practice in cities and, at the same time, unlock their associated co-benefits through the delivery of more widespread, connected, inclusive, and resilient NbS (Vierikko et al., 2016) (Fig. 1).

<Figure 1 Here>

1.3. Scope and aims

In the face of climate change, biodiversity loss, and unsustainable development, many fields of environmental management now see nature as part of the solution, and the time is right to extend these ideas to heritage conservation. To better integrate built heritage into NbS and urban GI frameworks, the different 'roles' of nature (whether positive, negative, or benign, and whether planned or spontaneous) must first be understood so that balanced, evidence-based decisions can be made (Viles, 2012; Favero-Longo and Viles, 2020). At the same time, the difficulty of striking this balance when faced with varied and complex heritage values must be acknowledged. Whilst some well-established greening interventions may be entirely inappropriate (or at least highly controversial) for heritage buildings and sites, there are opportunities for other, novel solutions. Plants are already successfully being used in some contexts to help address specific heritage conservation challenges, and yet these approaches

154 are rarely considered in urban greening initiatives. Furthermore, beyond active interventions,
155 a more informed and selective approach to the management of nature and wildlife on and
156 around built heritage can contribute to the delivery of resilient urban NbS.
157
158 Here, by providing a dedicated discussion of urban built heritage and NbS, we aim to (1)
159 situate built heritage and its conservation and management within existing NbS frameworks
160 and the wider urban greening paradigm by considering the particular risks, challenges, and
161 opportunities this presents; (2) explore the potential conflicts and trade-offs that emerge when
162 seeking to balance the negative and positive impacts of nature on and around built heritage;
163 (3) explore how built heritage can both benefit from and contribute to the wider
164 implementation of NbS in cities and the delivery of other environmental, economic, and
165 social co-benefits; and (4) suggest some future directions for better integrating built heritage
166 within the urban NbS agenda. Whilst not intended as an exhaustive review, our discussion
167 and ideas are based on a synthesis of selected examples from the literature as well as our own
168 experiences as academics working in heritage conservation research, often in collaboration
169 with professional heritage organisations in the UK.
170

171 **2. Recognising the barriers: 'nature as a threat' to urban built heritage**

172 In most cases, the primary management objective for built heritage is to ensure its long-term
173 conservation. Currently, 'nature' is widely considered a threat to built heritage for a range of
174 reasons, some real and some perceived, encompassing the roles of microbes, plants, and
175 animals in causing (1) direct physical damage (broadly termed 'biodeterioration'), (2) the loss
176 of associated heritage values (e.g., altering site aesthetics and authenticity), and (3)
177 obstructing or complicating day-to-day management and conservation practices (see Table 1
178 and discussion in subsequent sections). In the face of such threats, the drive to 'protect' built

heritage will likely take precedence over any broader motivation to deliver NbS benefits. At the same time, as one of the many challenges facing heritage conservators and decision-makers, the risks that living organisms pose for heritage buildings and sites must not be downplayed (ICCROM, 2016). Acknowledging these tensions and understanding how and where they operate are important first steps in reaching informed decisions about if, when, and how to manage them.

2.1. Nature as a threat to material heritage: biodeterioration

There is a large literature on the biodeterioration of stone, brick, and concrete (e.g., Lisci et al., 2003; Caneva et al., 2009; Cutler and Viles, 2010; Pinna, 2014). Relevant processes include, among others, biochemical decay via acidification, physical penetration of roots, and moisture retention linked to damp (see Favero-Longo and Viles, 2020, for a recent review). Research on these decay mechanisms has progressed from studies of individual species on single materials to the impacts of multiple species across large and complex sites (e.g., Caneva et al., 2015; Li et al., 2016; Morando et al., 2017). On building stone, much more research has been done on microorganisms and lichens than on higher plants and animals (e.g., Crispim and Gaylarde, 2005; Negi and Sarethy, 2019). Ivy is a notable exception that, alongside other woody vegetation, can cause—or at least exacerbate—serious damage in certain circumstances (Mishra et al., 1995; Bartoli et al., 2017; Coombes et al., 2017). For historic assets, the risks may be even greater owing to their age, traditional materials, construction type, and current state of repair. For example, in the case of plants growing on historic walls, the most serious problems arise when cracks and crevices associated with prolonged exposure to weathering agents (rain, frost, and repeated temperature fluctuations) or poor maintenance (e.g., loss of mortar pointing and unmaintained rainwater goods) are exploited by woody species and climbing plants (Coombes et al., 2017; Table 1). Many heritage buildings also house valuable

and highly sensitive artefacts and objects including artworks, textiles, and paper records, presenting additional conservation risks and, often, negative associations with 'wildlife' as potential pests (New, 2015; Querner, 2015).

<Table 1 here>

In response to these risks, actively preventing and/or removing vegetation and other types of growth (e.g., microbial biofilms, mosses, and lichens) using manual removal, acid-based cleaning, and biocide treatments is routine (Pinna, 2017) and may be applied often without question as a proactive and risk-averse approach to building conservation (Watt, 2016). Images of abandoned, neglected, and ruined buildings engulfed in vegetation are highly evocative (Woodward, 2002; Ashurst, 2007) and have arguably perpetuated a negative association between plants and building conservation (Wood, 2005). However, cause and effect links are not always clear (Viles et al., 2011), giving rise to a 'chicken-and-egg' dilemma where the nature of the associations between deterioration features (e.g., damp, surface staining, and cavities and crevices in walls) and ecological colonisation remains unclear. The dynamics of biodeterioration over time have also seldom been considered, and further research is required on the implications of natural succession and on-going environmental change for interactions between heritage materials and ecology (Viles and Cutler, 2012; Caneva et al., 2015). In cities, this includes shifts in air quality (e.g., Wilhelm et al., 2021) and enhanced urban heat island effects in the face of climate change, which may have knock-on consequences for wall ecology.

The challenge, then, is finding a suitable balance, where decisions can be made based on evidence and context rather than generally applied actions informed by assumed knowledge and concern for the worst-case scenario. For example, rather than the blanket removal of all

228 ‘green’ that naturally develops on heritage buildings and structures, organisations such as
229 English Heritage (2014b) call for a more selective approach; woody trees and shrubs rooted
230 into historic walls and clearly causing damage should be removed at the earliest opportunity,
231 yet soft herbaceous perennials, annuals, and lower plants can often be left. Such an approach
232 offers opportunities to complement and support wider efforts to implement NbS in cities and
233 incorporate heritage assets into the wider GI network (see Section 3).
234
235 *2.2. Nature as a threat to heritage values and conservation principles*

236 As well as the direct damage that organisms can cause to built heritage, their presence can
237 have negative influences on intangible heritage values encompassing issues of aesthetics,
238 authenticity, and presentation (Lowenthal, 2015). Given the contested nature of heritage, we
239 should be conscious that the push for renewal, revitalisation, and upgrading of urban
240 spaces—which increasingly includes greening and other NbS activities—risks eroding or
241 erasing valued cultural spaces and objects (Haase et al., 2017). As Dinnie et al. (2013) note,
242 experience of urban green space is inescapably social, being strongly influenced by social
243 positioning. This can lead to paradoxical effects through contested meanings between groups
244 and individuals, especially when valued heritage is involved, and runs the risk of insensitive
245 applications, as articulated through emerging discussions of ‘greenwashing’ and ‘green
246 gentrification’ in cities (Wolch et al., 2014; Schuetze and Chelleri, 2015; Pearsall and
247 Anguelovski, 2016; Efrat, 2018; Yazar et al., 2020).

248 Issues of aesthetics and presentation are particularly relevant for urban built heritage
249 (Rodwell, 2018). For example, where buildings are valued for architectural reasons,
250 obscuring important features of interest with vegetation ('bio-obscuration', Viles, 2012)
251 should be avoided. Tradition also comes into play, whereby heritage sites that have always
252 (or at least in recent memory) been clear of vegetation run the risk of being labelled

253 ‘inauthentic’ if plants are purposefully introduced or allowed to persist (Deghati Najd et al.,
254 2015). Similarly, as well as removing vegetation from buildings for valid conservation
255 reasons (see Section 2.1), the perception of neglect and an unkempt aesthetic is a strong
256 driver for active removal (English Heritage, 2014b; Table 1). In these respects, the
257 expectations of heritage managers and heritage consumers could limit or prevent the delivery
258 of potential nature-based benefits. One example is the ‘well-manicured lawn’, widely
259 considered a prerequisite of the historic house aesthetic with a tradition reaching back to at
260 least the 12th Century in Britain and the 18th Century in North America (Byrne, 2005; Smith
261 and Fellowes, 2013). Yet perfect ‘lawnscapes’ offer very little biodiversity value or
262 associated benefits (Smith et al., 2015), showing how trade-offs can arise when the desire to
263 present a certain heritage aesthetic precludes or even conflicts with NbS principles and aims.
264 Such opinion and received wisdom can change, however, as shown by the current growth in
265 the ‘more than weeds’ movement (Bonthoux et al., 2019). This promotes a more positive
266 perception of spontaneous flora on walls and pavements as a valuable component of urban
267 biodiversity rather than weeds to be managed and removed, and as an opportunity for public
268 engagement, education, and enhanced well-being (Myers, 2020; Vega et al., 2021; also see
269 www.morethanweeds.co.uk, accessed April 2021). Indeed, the perfect, tidy, mono-species
270 Victorian characterisation of what a lawn *should* be is also increasingly being questioned
271 (Smith and Fellowes, 2013), opening up opportunities for bringing a richer, biodiverse, and
272 naturalistic aesthetic to historic landscapes (Dunnett and Hitchmough, 2008).

273 *2.3. Nature as a threat to heritage conservation practices*

274 The challenges we have outlined have important practical implications for heritage
275 conservation that may further hinder the inclusion of heritage buildings and sites in urban
276 greening activities and networks. This might include vegetation obstructing or complicating
277 day-to-day use and routine maintenance and inspection activities as well as additional time

requirements and costs if existing practices need to be altered (e.g., Roy et al., 2012; Table 1). Concerns associated with specific species can also arise, including vegetation harbouring pests such as wasps and vermin in public areas. Paradoxically, whilst the presence of some legally protected species including bats, newts, and nesting birds can have positive connotations for biodiversity conservation and public engagement, these may also be perceived as restricting day-to-day site management (Bullock and Ferneyhough, 2013). Kowarik (2011) also considers maintenance costs as a potential risk associated with non-native species in urban areas. Perhaps most notably, the addition of green elements may be perceived to require additional time and cost commitments to ensure upkeep and care, such as watering in summer, alongside a need for new equipment and personnel skills and training, which may not always be welcomed when resources are tight (Akinshina and Azizov, 2008).

This links to broader discussions about 'ecosystem disservices' and 'nature as nuisance' in urban areas (Lyytimäki et al., 2008; von Döhren and Haase, 2015). These concepts recognise that interventions aimed at increasing greenness and biodiversity do not "necessarily mean only richness of goods and services, but also a richness of nuisances" (Lyytimäki and Sipilä, 2009, p310), such as the need to prune, weed, and water (Table 1). The potential for such 'nuisance' can be particularly strong in the case of highly valued, sensitive, and legally protected heritage buildings and sites, necessitating an informed and cautious approach to NbS decision-making that maximises benefits whilst minimising risk.

Where NbS are actively implemented for heritage conservation (Section 3.1) or where a decision is made to manage natural elements in a different way (e.g., selective rather than blanket removal of vegetation from walls), the ways in which heritage assets are managed as places people choose to visit and engage with may also need to change. This could involve a greater effort to communicate decisions to visitors to address potential concerns. One such example is at Godstow Abbey in Wolvercote, Oxfordshire, a Scheduled Monument managed

by the University of Oxford. Here, a local community group raised concerns about 'weeds' and a lack of general upkeep of the walls of the abbey. In fact, the structure was being used as part of a research trial our team were conducting in collaboration with Historic England on vegetation as protective 'soft capping' (see Section 3.1). Whilst requiring some additional time and resources, by engaging with the community and communicating the purpose and benefits of the vegetation that had been left or added to the walls, we fostered a greater appreciation for the plants and support for developing NbS for heritage conservation more broadly.

These approaches not only require robust evidence of potential threats but an efficient means of communicating and enabling asset managers to adjust existing practices accordingly. In the UK, key organisations such as English Heritage, Historic England, and the National Trust can play important roles through industry focussed publications and collaborative research with academics (Bullock and Ferneyhough, 2013; English Heritage, 2014b; Coombes et al., 2017; Wood et al., 2018). End-user-targeted assessment tools that enable practitioners and decision-makers to weigh-up the potential costs and benefits of NbS compared to 'business as usual' also have a significant role to play (Naylor et al., 2017; Bouzouidja et al., 2021) but more effort is needed to bolster the supporting evidence in the case of valued heritage assets and the particular risks involved.

3. Unlocking the opportunities

To address the range of identified challenges, in this section we highlight opportunities to combine built heritage conservation and the delivery of NbS in cities for mutual gain. We suggest three main ways this could be achieved. First, NbS could be adapted, developed, and applied to address specific heritage conservation challenges. Second, the wider benefits of NbS (as implemented for other environmental, social, and economic reasons) for built

heritage conservation should be recognised and promoted. Third, we suggest various ways in which built heritage conservation can help enhance and diversify the delivery of NbS and their associated co-benefits in cities. Under this framework, we aim to initiate discussion on how the inclusion of built heritage conservation within the broader NbS framework offers opportunities for both sides.

3.1. Nature-based solutions for the conservation of built heritage

The flip-side of biodeterioration is that there are many ways in which biota can retard rather than enhance the deterioration of building materials. These include shielding colonised surfaces from other agents of decay (i.e., rain, UV radiation, pollutants, and other weathering and erosion agents) and the direct consolidating effects of some organisms, collectively termed 'bioprotection' by the geomorphological community (Naylor et al., 2002; Carter and Viles, 2005). In contrast to the volume of research on biodeterioration, far less has been done on bioprotection. Nevertheless, there is growing evidence that some higher plants and algal- and lichen-rich biofilms can be protective (e.g., Carter and Viles, 2003; Sternberg et al., 2010, 2011; Viles et al., 2011; Hanssen and Viles, 2014; Jroundi et al., 2017; Favero-Longo and Viles, 2020). For example, Cutler et al. (2013) provide evidence that green algal biofilms reduce moisture ingress on sandstone walls in Belfast, and Coombes et al. (2018) used microclimate data and laboratory simulations to show how a cover of ivy (*Hedera helix*) can reduce frost damage to historic limestone walls in Oxford. At the whole-building scale, evidence from ruined sites also shows that tree cover can reduce the potential for stone deterioration via microclimatic thermal buffering effects (André et al., 2012, 2014). Similar conclusions have drawn based on the modelled effects of tree shading on the Nanjing City Wall, East China (Li et al., 2021), which forms part of the 'City Walls of the Ming and Qing Dynasties' entry on China's Tentative List of UNESCO World Heritage sites.

Recognising the protective roles of some naturally occurring organisms, there has been some effort to apply this knowledge as a NbS. For example, 'soft capping' is increasingly seen as a nature-based way of protecting vulnerable wall tops at (largely ruined) heritage sites (Wood et al., 2018). The technique involves the use of soil and vegetation to consolidate the tops of exposed masonry structures, reduce rainwater ingress, and buffer temperature-related weathering processes (e.g., Hanssen and Viles, 2014). As well as offering an effective and more sustainable conservation strategy alongside other potential benefits including biodiversity gains, soft capping is more cost-effective and easier to maintain than the business-as-usual approach of using 'hard' stone and mortar capping (Naylor et al., 2017; Wood et al., 2018). Furthermore, surveys at test sites in the UK indicate that when coupled with public engagement and education, soft caps can be aesthetically appealing to visitors (Wood et al., 2018). Currently, soft capping has been applied to range of sites in England, Scotland, Turkey, Belgium, Sweden, Sierra Leone, and USA (Morton et al., 2011; Lim et al., 2013; Wood et al., 2018; Miller, 2019).

While practical heritage conservation interventions like soft capping have many similarities with more widely adopted NbS, they have not typically been viewed in this light, especially in urban contexts. Applying the concept of NbS could help highlight the wider benefits of such interventions that could address other social challenges at the same time (see Section 3.3). Several knowledge gaps remain, however. For example, with the exception of soft capping, there have been almost no studies on people's perceptions of natural elements—whether added or spontaneously developed—on and around heritage sites. Importantly, for NbS to be 'deployed' more widely in heritage conservation, these approaches must be carefully balanced against the potential threats outlined in Section 2.

3.2. Wider potential benefits of nature and NbS for built heritage conservation

Ten key benefits of NbS in urban contexts have been articulated by Xing et al. (2017), specifically improving health, sequestering carbon, enhancing biodiversity, providing acoustic comfort (baffling unwanted noise), reducing the urban heat island, enhancing sustainable water management, facilitating urban agriculture, improving air quality, contributing to economic vitality through jobs and investment, and enhancing social cohesion. Whilst evidence and implementation tools for each of these benefits are growing in a range of urban contexts (e.g., Naylor et al., 2017; Andersson et al., 2019; Pauleit et al., 2019), to our knowledge, there has been no holistic consideration of how such benefits might be achieved and supported by 'greener' built heritage conservation.

In Table 2 (left-hand column), we suggest a range of broad ways in which commonly identified benefits of urban NbS might also benefit built heritage conservation. This includes potential reductions in damaging pollutants reaching vulnerable historic stonework by particulate-trapping street trees, green walls, and other forms of vegetation (e.g., Sternberg et al., 2010); associated reductions in flood risk and water damage to heritage assets through sustainable urban drainage systems and bioswales in flood-prone urban centres (e.g., Porębska et al., 2019); and the creation of more attractive, peaceful, comfortable, and healthy urban spaces for those visiting and working in and around heritage buildings and sites (e.g., Kim et al., 2019; Table 2). In the latter case, improvements to the 'heritage environment' though the addition of green elements might offer broader social and economic opportunities by making sites more desirable to visitors, increasing footfall, and attracting investment (Adinolfi et al., 2014). Nature also offers opportunities for communities to engage with their heritage in new ways. This might include active engagement through education on the linkages between heritage conservation and contemporary environmental issues such as biodiversity loss and climate change or simply boosting the aesthetic appreciation of a site (e.g., Wood et al., 2018; Vega et al., 2021).

403

404 <Table 2 here>

405

406 The strength of the linkages outlined in Table 2 will vary widely depending on a range of
407 factors including (1) the type of built heritage considered and the specific
408 threats/conservation challenges it faces now and in the future; (2) the types and extent of NbS
409 being implemented on and in the vicinity of built heritage assets; and (3) the values, attitudes,
410 and perceptions of those managing and consuming the heritage (see Sections 2).
411 Nevertheless, by recognising that urban NbS can offer a range of additional benefits for
412 heritage conservation (Table 2), we hope to highlight potential avenues for overcoming some
413 of the potential conflicts.

414

415 *3.3. Benefits of built heritage conservation for the delivery of urban NbS*
416 Column 3 in Table 2 illustrates how heritage conservation can contribute to the broader urban
417 greening paradigm. Environmentally, built heritage should be more widely included in
418 discussions of 'novel' urban habitats (Collier and Devitt, 2016) and as contributors to urban
419 biodiversity and ecological connectivity. For older heritage in particular, the 'uniqueness' it
420 provides with respect to habitat types and the species and communities it can support offers a
421 potentially richer, culturally valued way of conserving urban nature. For example, urban
422 walls support a wide range of lower and higher plant species (see Francis, 2010), and old
423 walls in particular offer a broad range of substrate types and physical niches less frequently
424 disturbed than other urban habitat patches. This might favour novel, long-lived communities,
425 with field boundary stone walls offering a useful analogue (Collier, 2013; Grove et al., 2020).
426 Industrial heritage landscapes are also increasingly recognised as having significant and

unique biodiversity value, perhaps best demonstrated by the Duisburg-Nord Park in the Ruhr Valley, North Rhine-Westphalia, Germany. Here, plant species from more than 700 tribes have been recorded including almost 50 on the Red List, for which the walls of buildings and temporary water bodies are important habitats (Keil, 2019). NbS for heritage conservation can also contribute to biodiversity, such as in the case of soft capped walls, on which trials in the UK have recorded spontaneous colonisation by a range of native flora (Wood et al., 2018).

As well as buildings and walls, the gardens and other land within heritage sites offer additional spaces for biodiversity in built-up urban areas. For example, historic or 'legacy' green urban spaces are often closely associated with heritage and, as such, their mutual management and conservation could be highly advantageous. In Europe, America, and elsewhere, cemeteries and churchyards are common even in built-up areas, and not only contain many forms of tangible and intangible heritage but also function as semi-natural spaces that can deliver a range of environmental and cultural services (Skår et al., 2018; Quinton and Duinker, 2019; Quinton et al., 2019). Cultural and natural values need not be mutually exclusive in such spaces but may, in fact, be strengthened when considered together. Facilitating public engagement with cemeteries as green urban spaces, for example, has been shown not only to improve mental health and well-being but also foster a sense of respect and value for them as heritage spaces (Swensen and Skår, 2019; see Section 3.2). Built heritage might also offer additional value when included in other urban NbS initiatives. In the historic city of Padua, Italy, for example, Campagnaro et al. (2020) used photo mock-ups and visitor surveys to suggest that the presence of historic walls in urban green spaces can enhance their stress-relieving potential.

This integrated way of thinking aligns with the concept of biocultural heritage in which nature can more directly be considered a component—and in some cases co-creator—of heritage in cities (Buizer et al., 2016; Elands et al., 2019). For example, various authors have noted the historical associations between rare and medicinally useful plants and monasteries and castles (Conolly, 1994; Solberg et al., 2013) as well as the contributions of wildlife to the aesthetic of monastic, industrial, and urban ruins (Ferraby, 2007; Wood, 2005; DeSilvey, 2017). In some heritage contexts, such as abandoned and ruined sites, ecology becomes more entwined in the development and modification of heritage value through associated aesthetics (DeSilvey, 2017). In this sense, actively greening cities using NbS or managing the spontaneous colonisation of heritage assets over long periods of time might co-create new forms of biocultural heritage (Vierikko et al., 2016; Huang et al., 2019) and even alleviate tensions between urban development, mass tourism, and heritage conservation in historic cities (Opschoor and Tang, 2011; Dinnie et al., 2013).

Heritage conservation can also contribute to the delivery of NbS at a practical level, as fuller integration of cultural perspectives and values into NbS frameworks should help account for the value-orientations of a greater range of stakeholders (e.g., Buizer et al., 2016). Valuing and managing spontaneous flora on walls and buildings differently, for example, might not only support wider urban biodiversity goals but also enhance perceptions of age, legacy, socio-ecological memory, and continuity (Andersson and Barthel, 2016). This has particular relevance in rapidly (re)developing historic cities where tensions between the past and the future can be especially challenging. These ideas offer significant opportunity for joined-up thinking in cities (Harrison et al., 2020) but remain underexplored for many forms of urban heritage.

Finally, heritage sites can offer inspiration from the past for urban NbS initiatives today. This includes traditional fruit and vegetable growing in historic gardens and orchards (English

Heritage, 2014a) as well as other forms of production including honey and associated crafts, which could inspire the design of urban agriculture and gardening schemes (e.g., Caneva et al., 2020; Sunguroğlu Hensel, 2020). Historical knowledge and practices could further provide useful models for the sustainable management of urban water (Ortloff, 2014). More broadly, the materials, designs, and construction practices of heritage structures might offer inspiration for mimicking or enhancing the bioreceptivity of modern urban design (e.g., Jim and Chen, 2011). By exploring these associations more closely and in a greater range of contexts, the presence of built cultural heritage and the conservation and recognition of its natural elements should facilitate the wider delivery, connectedness, and inclusivity of NbS (Table 2).

4. Joining the dots and scaling things up

Given the mounting evidence of the benefits of NbS in cities and a strengthening steer from policy, there is now a push to 'up-scale' efforts by extending and linking successful approaches across the cityscape (Cohen-Shacham et al., 2019; Zhang et al., 2019; Dumitru et al., 2020; IUCN, 2020; Babí Almenar et al., 2021). Despite some valuable progress (Pauleit et al., 2019), the mechanisms and conditions for up-scaling remain poorly understood and involve a range of ecological, institutional, and socio-cultural challenges (Fastenrath et al., 2020). In heritage-rich urban areas, built heritage should be recognised as a component of this complexity, which introduces specific and sometimes unique issues (Section 2) that require creative thinking and novel solutions (Section 3).

A hybrid greening/heritage conservation approach is, therefore, likely required. For example, opportunities for implementing GI and other NbS should be identified in a way that accounts for—and even enhances—existing heritage values and conservation needs. In addition to the specific examples outlined in Table 2, some promising larger-scale examples exist. At a city

scale, as part of efforts to mitigate the urban heat island in the UNESCO World Heritage Site of Malacca City, Malaysia, greening opportunities have been identified within the constraints of existing heritage management plans (Saito et al., 2017). In Germany, the 'Green Belt Berlin' scheme involves the transformation of approximately 13 km of fortified structures in the former border zone of the Berlin Wall into a greenway, showing that integrating heritage structures and 'wild' urban nature can lead to attractive and reconciliatory greenspaces (Kowarik, 2019). In this case, management practice has been altered to allow the natural recolonization of walls, yielding both biodiversity, aesthetic, and social benefits. Such larger-scale NbS ambition that incorporates and connects parks, woodlands, and other green recreational spaces with built heritage in new and mutually beneficial ways has rich potential (Parker and Simpson, 2020). As Cohen-Shacham et al. (2019) suggest, identifying synergies between different solutions at the landscape scale is key to the success of NbS. This can support calls for integration across sectors, actors, and countries as the key to resilient and sustainable cities (Stafford-Smith et al., 2017).

Based on the range of potential linkages outlined in Table 2, some key themes emerge for linking heritage conservation and NbS in cities, summarised in Table 3. First, built heritage conservation can benefit from the implementation of NbS that (1) reduce or mitigate the deterioration of heritage materials, (2) improve the visitor experience, and (3) contribute to resilience by enhancing values and simulating investment. Second, built heritage conservation can support the delivery and success of NbS in cities by (1) offering additional locations to implement and connect NbS schemes, (2) providing inspiration for closer relationships between nature and society, and (3) enriching NbS benefits by adding a cultural element.

<Table 3 here>

Moving forward, the recent IUCN (2020) Global Standard for NbS provides a useful framework for future research. This proposes the following eight criteria for the design and scaling up of NbS: (1) effectively address societal challenges; (2) consider scale in their design; (3) deliver biodiversity net gain; (4) ensure economic viability; (5) be based on inclusive, transparent, and empowering governance; (6) balance trade-offs between primary goals and provision of co-benefits; (7) be managed adaptively and based on evidence; and (8) be sustainable and mainstreamed within an appropriate jurisdictional context (IUCN, 2020). We hope that the ideas in this paper will provide a starting point for addressing Criterion 1 in the specific context of urban built heritage, but further work is required to consider how heritage conservation in cities can benefit from and contribute to all of these criteria. Whilst all have implications for integrating built heritage conservation and NbS, the ideas and examples outlined in Table 2 indicate that issues surrounding the trade-offs between the provision of multiple benefits (Criterion 6), the need for evidence-based management decisions (Criterion 7), and operating within the appropriate jurisdictional context (i.e., the legal framework for heritage designation in this case) (Criterion 8) seem particularly crucial areas for research. This is work that the heritage community should fully engage with alongside urban geographers, ecologists, and planners to ensure that heritage is not excluded from the wider discussion and implementation of NbS and, at the same time, heritage conservation principles are accounted for and enhanced wherever possible.

4. Conclusions

The notion of heritage conservation practice as something that is ever-changing, adaptable, and resilient lends itself to embracing the new opportunities and paradigms of urban greening and NbS. Opportunities should be sought for the heritage in our cities whilst ensuring a

552 measured, evidence-based concern for its conservation and value enhancement.
553 Fundamentally, we argue that adopting NbS in these contexts requires some flexibility and, in
554 some cases, modification of existing approaches and perceptions to account for the particular
555 requirements of managing vulnerable and highly valued heritage. The opportunities are rich;
556 using nature to help conserve built heritage is already yielding novel forms of NbS that have
557 not typically been included in the urban NbS 'toolbox'.
558
559 This is important so that heritage is not discounted or devalued in the rapidly changing
560 modern city. We encourage built heritage in cities to be seen as a unique opportunity for NbS
561 rather than as a barrier founded on generalised perceptions of nature as a threat to materials,
562 values, and practices. Whilst it may not always be possible, opportunities should be sought
563 for NbS to enhance the values ascribed to heritage buildings and sites, allowing the public to
564 engage with them and with nature in new, positive ways. For example, coupled with a greater
565 effort to identify which species are damaging, protective, or benign for heritage (Section 2),
566 exploring the functioning of built heritage as novel habitats and the unique—and sometimes
567 rare—ecology it supports should supplement efforts to bring nature into the city, conserve it,
568 and use it to help address urban societal challenges.

569 Finally, the United Nations (UN) Sustainable Development Goal 11 has the overall aim of
570 making cities and human settlements safe, resilient, and sustainable. To achieve this, one of
571 the 10 targets set is to strengthen efforts to protect and safeguard the world's cultural and
572 natural heritage. This recognises that cultural and natural heritage are vital components of
573 resilient and sustainable communities, fostering shared values by connecting people with
574 their surroundings, the past, and with nature. Employing NbS to address heritage
575 conservation challenges in cities and, at the same time, unlocking the potential for heritage

conservation to contribute to their wider delivery, connectivity, and resilience offers exciting potential for win-win solutions.

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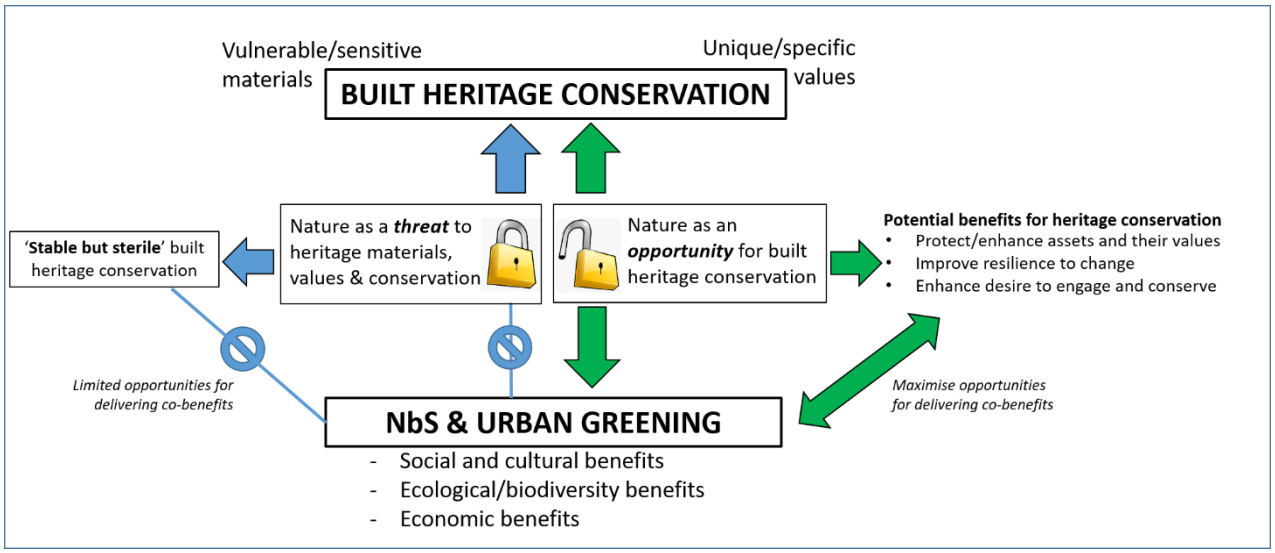
Figure Captions:

Figure 1. Unlocking the opportunities of integrating nature-based solutions (NbS) and built heritage conservation in cities. The broad assumption that nature is a 'threat' to heritage materials, values, and practices fosters a 'stable but sterile approach' to heritage conservation (left-hand side of the diagram). Alternatively, recognising the opportunities that nature offers for heritage conservation can 'unlock' the full range of benefits that greening and other NbS approaches can deliver in cities (right-hand side of the diagram).



Coombes and Viles Figure 1.

Table 1. A non-exhaustive categorisation of 'threats' associated with natural/green elements on and around heritage buildings, walls, and ruins.

Category of threat	Example process/action	Potential challenges for heritage conservation*
Material damage (biodeterioration)	Not removing/ allowing vegetation to naturally colonise historic walls	Woody shrubs and trees colonising walls (e.g., ivy and buddleja) can loosen mortar, enlarge cracks and existing defects, and cause serious structural damage.
Loss of heritage values and negative perceptions	Natural/green elements changed or added on/in and around heritage sites	Altered aesthetic and presentational character; Bio-obscuration of valued architectural detail; Negative visitor perceptions (e.g., neglected, unkempt, poorly managed, etc.); Compromised authenticity, historical character, and heritage designation.
Obstructed/altered conservation practices	Altered/new green elements change management and maintenance requirements and frequency	Slower/missed detection of serious structural issues requiring early intervention; New skills and equipment required for day-to-day maintenance; Additional costs of upkeep (e.g., watering and weeding).

*note that the listed challenges for heritage conservation are based on widely held perceptions and do not necessarily apply in all cases (also see Section 3).

924 **Table 2.** Examples of potential co-benefits and linkages between nature, NbS, and built heritage conservation in urban areas.

Benefits of NbS in cities (after Xing et al., 2017).	**Benefits of NbS for built heritage conservation in urban areas**	**Benefits of built heritage conservation for the successful delivery of NbS in urban areas**	**Examples**
Health impacts	Attractive green spaces encourage engagement with the urban landscape; more and happier visitors to heritage sites in cities.	Including cultural elements in NbS can help enhance well-being. Connections to the past and engagement with culture foster a sense of place and improve mental health.	Engagement with urban cemeteries as green heritage spaces improves calmness and self-esteem (Swensen et al., 2016).
Urban heat island (UHI) mitigation	Reduced exposure of vulnerable materials to thermal cycles and extremes in cities. Buffered microclimates improve conditions for those living in, working at, and visiting historic buildings and sites. Reduced energy demand for heating/ cooling historic buildings.	Heritage sites provide additional locations for UHI mitigation projects in cities. Green approaches to heritage conservation can provide local-scale buffering.	Ivy on historic walls reduces the frequency and magnitude of potentially damaging extreme temperatures (Coombes et al., 2017, 2018).
Carbon sequestration	Reductions in chemical weathering potential in urban areas (e.g., less acidic environment and	Heritage sites provide additional locations to contribute to climate change mitigation	Holistic management and conservation of historic cities can contribute to urban

	soiling). Improved sustainability credentials of heritage assets/sites.	through local-scale sequestration. NbS to heritage conservation challenges could provide local-scale sequestration benefits.	sustainability by supporting ecosystem services across the full range of heritage assets (including grey, blue, and green types), such as carbon sequestration by salt marsh and seagrass habitats in Venice Lagoon, Italy (da Mosto et al., 2020).
Biodiversity	Improved attraction and value of greened areas to visitors. Enhanced motivation to conserve heritage as an urban habitat resource. Some species have cultural significance that contributes to heritage values.	Heritage buildings and sites can provide additional habitat space in urban areas. Built heritage can support novel, rare/endangered, and relict biota and contributes to biodiversity conservation.	Historic walls function as novel habitats in urban areas (Francis, 2010) and wall flora have cultural associations and values (e.g., Lo and Jim, 2015).
Sustainable water	Reduced risk of water-related damage to heritage assets and sites, e.g., flooding and water ingress to historic buildings.	Heritage sites offer additional locations for sustainable water management schemes in cities, and provide historical examples of successful low-tech approaches to water management.	Engineering knowledge of ancient civilisations provides inspiration for modern sustainable water management (Gonzalez Cruz, 2017).
Urban agriculture	Produce grown and sold at heritage sites can provide additional income to support	Many heritage sites provide examples of productive urban agriculture (e.g., kitchen	Fruit growing has a long tradition at heritage sites, helping preserve heritage varieties, and

	upkeep/conservation activities, e.g., bee products, vegetables, and cut flowers in historic gardens. Heritage sites can be valued as productive spaces for traditional fruit and vegetable cultivation and horticultural skills.	gardens and traditional orchards). These could be enhanced, reinstated, or used to inspire new schemes. Modern heritage sites, buildings, and institutions provide additional locations for urban agriculture.	horticultural skills and traditions alongside other benefits to biodiversity and people (English Heritage, 2014a).
Air quality	Improved air quality reduces chemical degradation of vulnerable building materials; reduced soiling/discolouration of walls and buildings. Improved external and internal air quality for those living in, working at, and visiting heritage buildings and sites.	Heritage sites offer additional locations for air-quality management projects. Green approaches to heritage conservation can contribute to local-scale particulate filtration.	Vegetation on and around historic walls traps airborne particulates and limits surface soiling (Sternberg et al., 2010).
Acoustic	Reducing noise pollution in cities can help preserve the unique 'acoustic heritage' of some sites. Provision of quiet and peaceful spaces for those living in, working at, and visiting historic buildings and sites.	Many heritage sites offer quiet (traffic-free) spaces in cities and offer additional locations for acoustic management projects. Appropriate planting and landscaping at heritage sites provides local-scale acoustic buffering.	Acoustic comfort is considered crucial to the sustainability of route-based heritage tourism in cities (Sheng and Tang, 2015).

Jobs and investment	Heritage buildings and sites could benefit from the 'honeypot effect' of urban redevelopment projects that increasingly include NbS. Increased visitors to areas receiving investment can enhance public interaction/ engagement with heritage as a valued component of the modern city.	Using NbS to improve the management and conservation of built heritage supports a more resilient heritage sector, which can attract investment in urban areas and create jobs. Heritage crafts and traditional practices can provide opportunities for investment in NbS, e.g., local reed production for thatch, willow for basket weaving, and horticulture.	Employment in sustainable tourism, and tourism revenue, can be enhanced in historic cities through the incorporation and conservation of green spaces (Adinolfi et al., 2014).
Social cohesion	Healthy, green, cohesive communities bolster heritage values, and sense of ownership and stewardship of local heritage. Nature provides more opportunities/additional ways for people to value and engage with their local heritage.	NbS can help to manage, conserve and enhance locally, regionally, and nationally valued assets and sites. Heritage buildings and sites provide opportunities for green enterprise and community engagement (e.g., volunteering, education, etc.).	Integration of culturally valued sculpture, memorials and planting in community gardens fosters social cohesion and reconciliation (Gough, 2007).

928 **Table 3.** Key themes and opportunities for integrating built heritage conservation and nature-based solutions (NbS) in cities (see Table 2 for
929 specific examples under each of these themes and discussion in the main text).

Key themes	Opportunities for NbS to contribute to built heritage conservation.	Opportunities for built heritage to contribute to the success of urban NbS.
1	Reducing deterioration of heritage materials (e.g., through UHI mitigation and air quality improvements).	Providing more potential locations to implement and connect NbS schemes (e.g., air quality, UHI mitigation, and biodiversity conservation).
2	Improving the visitor experience/ conditions for those living and working in built heritage (e.g., through air quality, acoustic, and opportunities to engage with nature).	Providing historical examples of closer relations with nature (e.g., sustainable water management and urban agriculture).
3	Enhancing value of built heritage and improving its economic resilience (e.g., through jobs and investment, urban agriculture, and biodiversity).	Enhancing and diversifying the benefits of NbS by adding a cultural element (e.g., for health, biocultural diversity, and social cohesion).

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