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Improving the climate resilience of European cities via socially acceptable nature-based solutions

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Introducing nature based solutions (NBS) into urban areas is a challenging task for climate change mitigation and adaptation. However, the impact and effectiveness of NBS contingent upon the social acceptability of implemented measures. This study uses a dynamic and adaptive social acceptance framework that shows how data-driven science can inform the integration of NBS into cities while also ensuring that the public embraces these solutions. We apply the framework to four different cases: METU Forest in Ankara, Tisza River Bank in Szeged, Forest Garden in Alcalá de Henares, and Quarries in Milan. The results indicate that the key factor affecting social acceptance are procedural and distributive fairness, perceived risks, costs and benefits, knowledge, experience, and personal norms. Perceived benefit is the single common driver that directly affects social acceptance across the four case studies. Understanding the risk and benefits of an NBS and developing personal norms related to the environment will contribute to the improvement of resilience.

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INTRODUCTION

Climate change and the idea of achieving sustainable approaches to mitigate its impacts or adapt to changing climate are among the most complex and challenging problems humanity faces at the dawn of the twenty-first century. The world population that lives in urban areas was estimated by CIA[1] to be 56.6% in 2021; however, United Nations[2] projects that it will be 68% by 2050. This rate is expected to be 80% in Europe by 2030. Hence, improving the resilience of urban regions to climate change is essential to ensure that future generations enjoy the same quality of life as the current generation. Nature-based Solutions (NBS) are promising ways to meet the urban challenges associated with climate change[3].

The European Commission defines NBS as "solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience." They emerged as an effective approach to further develop the alignment between water[4–7], biodiversity[4,8], energy use[9], climate change mitigation[8], adaptation[9], and sustainable development objectives[10]. Mitigation and adaptation policies and tools, including those related to climate change, are typically assessed by their technical and economic feasibility and associated environmental and economic impacts. Nevertheless, the smooth and effective implementation of policies and wide adaptation of new products and concepts (i.e., NBS, renewable energy technologies[11], nanomaterial use in medicine, robotics, etc.) require social acceptance in addition to technical and economic feasibility.

The attempted targets may not be achieved smoothly due to the social, economic, technical, and environmental barriers once a policy intervention is implemented. The recent conflicts, particularly those associated with the selection of appropriate energy technologies[12–14], have underscored the importance of considering human interactions with environmental systems in planning for a more sustainable future[15]. Social acceptance is one of these critical dimensions imperative in planning and implementing policy interventions related to NBS and other sustainability improvements[7,16,17]. However, social acceptance has traditionally been considered solely in the last stage of planning processes, which prevents the incorporation of findings from acceptance studies into policy design and planning procedures. This is referred as a 'social gap', which states that it is critical for acceptance factors to be measurable to operationalize and predict acceptance reliably[18]. Developing a generalizable approach to studying the social acceptance of NBS is particularly important and challenging for several reasons. First, the implementation process of NBS involves interventions that are embedded in highly complex socio-ecological systems of which the responses are uncertain[19]. These interventions include measures that have large-scale landscape impacts. Under these circumstances, place attachment becomes crucial in the determination of attitudes. While acceptance is shown for NBS that support environmental conservation, opposition is shown towards interventions that bring about drastic deviations from the status quo or the idealized environment[19]. Second, the implementation of NBS happens over a long period of time. The lag times between the implementation and observation of the benefits of NBS and the potential for 'competing for societal interests both in the short- and long-term' increases reliance on social acceptance in these settings[20]. Third, the planning and implementation of NBS often involve collaboration among multiple stakeholders with diverse backgrounds and perspectives on how to approach solutions. Therefore, the public needs to trust all participating actors. Nonetheless, recent research on the implementation of environmental projects has revealed a significant decline in trust in decision-makers and increased demand for inclusivity and transparency, which underlines the importance of co-creative processes in which there is increased citizen engagement in nature-based adaptation planning[21]. Finally, existing studies on social acceptance are fragmented and cross-disciplinary, making it difficult to directly compare the acceptance of different cases. The approach developed in this study provides a common theoretical background that allows for

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more meaningful comparisons. Integrating a 'public communicative feedback loop' in the planning process of NBS will enable plans to adapt to reflect the locally important issues and help avoid potential pitfalls in a timely manner. In order to include social acceptance in feasibility or impact assessments and plans, social acceptance must be quantified like economic, technical, and environmental criteria; however, measuring social acceptance and identifying its main determinants is challenging because it cannot be directly observed. Even though it can be considered a latent factor inferred from measurable items, studies exploring the antecedents of social acceptance typically employ various methodologies. Therefore, it is challenging to aggregate acceptance data so that it can be directly employed in technical analyses. Moreover, while there are examples of quantitative methods, such as the NBS planning support system (PSS)[22] that allow stakeholder preferences and priorities to be incorporated into the planning of NBS, it is recommended that these methods be used in combination with other planning and engineering tools to ensure system validity. Understanding the linkages between individual behaviour and sustainable interventions requires complex, dynamic, adaptive, and multidisciplinary approaches[17].

In this paper, relying on behavioural theories, we aim to show how to utilize data-driven science to integrate and upscale various NBS into cities to improve climate resilience while ensuring that the public embraces the solutions. In particular, we use a comprehensive, dynamic, and adaptable framework for developing questionnaires to collect primary data about the social acceptance of different NBS. The intention is that the collected data could be integrated as inputs into sustainability assessments. This approach will not only complement the NBS PSS but will also guide systemic interventions in the implementation of NBS by allowing us to discern the reasons that produce unique social, economic, and cultural barriers to NBS in different communities[23]. To demonstrate this potential, we examine four NBS cases that delineate significant natural and cultural variation, namely METU (Middle East Technical University) Forest in Ankara, Turkey; Tisza River Bank in Szeged, Hungary; Forest Garden in Alcalá de Henares, Spain; and Quarries in Milan, Italy and discuss how quantitative evidence can be utilized to develop policy instruments and management strategies for longstanding public support. These cases show that our adopted behavioral model is reliable, generalizable, and comparable. As literature suggests[24], NBS interact uniquely with their surroundings. Therefore, the solutions employed in each location must reflect the sensitivities of its socio-spatial context. This means that it would be incorrect to assume a single intervention would fit all and that successful NBS can be copied from one place to another[24]. Instead, we must make sure that solutions capture communities' cultural, ethnic, political, social, and economic diversity and account for variations in beliefs, values, and concerns of the individuals that make up those communities. This research demonstrates how we can employ a data-driven strategy to better understand the varied perspectives of different communities and tailor the implementation of NBS to reflect these differences.

In the following sections, we provide a more detailed definition and discussion of social acceptance in the context of NBS. We present a framework encompassing the psychological factors that underlie and influence attitudes toward NBS. We elaborate on our research method, specifically our approach founded upon partial least squares, country peculiarities, and survey design. Following this, we present our findings for four selected cases of NBS. We discuss how putting NBS in larger structures influenced by social and ecological factors can help communities adapt to climate change.

RESULTS

Defining social acceptance

It is important to define and comprehend social acceptance to discuss its implications for the implementation of NBS. There are numerous studies in the policy literature have provided useful conceptualizations of social acceptance with a lack of consensus on the definition of the term. For instance, Kraeusel and Möst[25] define social acceptance as: "[a focus group or society's] positive attitude towards an issue at a determined point of time which is expressed in a certain opinion or a certain behaviour such as endorsement, approval, approbation." As indicated in previous related works[26], Kraeusel and Möst[25] do not provide a clear indication as to which types of attitudes or behaviour would be sufficient to constitute acceptance.

Cohen et al.[26] draw from the literature on economic utility and welfare theories to define social acceptance in a way that allows for its quantitative assessment. The authors choose not to define acceptance in terms of the presence of opposition, or lack thereof, but rather suggest that social acceptance will be achieved when welfare impacts are balanced and there are no Pareto improvement possibilities[26]. Welfare-decreasing attributes could include elements such as noise, ecological change, and safety concerns, among others. Whereas welfare-increasing aspects could include elements such as green benefits, economic development, and an increase in property value[26]. Our approach to understanding social acceptance does account for these welfare-increasing and welfare-decreasing attributes. However, it is essential to include other behavioral factors such as knowledge, experience, and trust to better account for potential pathways to achieving favorable solutions. Therefore, we adopt a more general definition, as provided by Upham et al.[27], social acceptance is "a favorable or positive response (including attitude, intention, behavior and -where appropriate- use) relating to proposed or in situ technology or socio-technical system by members of a given social unit (country or region, community or town and household, organization)," However, we recognize that this definition requires the social unit of interest to be identified. We refer to Wüstenhagen et al.[9] to establish the scope of interest.

In the context of renewable energy project implementation, there exist three dimensions of social acceptance: socio-political acceptance, community acceptance, and market acceptance[7]. Wüstenhagen et al. [9] define the socio-political dimension as being inclusive of the acceptance of technologies and policies and the acceptance by the public, key stakeholders, and regional and local policymakers. Socio-political acceptance is the broadest dimension because it may apply to policies and technologies. On the other hand, community acceptance is about whether or not local stakeholders agree with where a project should be built. Given that the location of the project is of interest, aspects like procedural justice (i.e., the inclusion of all stakeholders in decision-making), distributive justice (i.e., the fair distribution of benefits and costs); trust related to the intentions and competence of decision-makers, and the evolution of acceptance over the entire project timeline are called into question. Finally, market acceptance concerns the process of innovation and market adoption and considers the interdependent paths and attitudes of consumers, investors, and firms. Community acceptance refers to acceptance by local stakeholders directly exposed to the NBS. In contrast, market acceptance refers to acceptance by a broader stakeholder set from the supply, demand, and investment sides.

This three-fold view of social acceptance can also be applied to developing and implementing NBS. As NBS involve both physical and technical interventions in geographical locales[28,29], they are subject to socio-political acceptance. In that respect, recognizing the importance of the interventions made by local, regional, and national audiences is a relevant consideration. In terms of community acceptance, as NBS may consume public space or

be located near a historical site or residential area, it has associated burdens and benefits that impact multiple stakeholders[30–33]. Thus, the community's acceptance of NBS will likely depend on how fair and inclusive the decision process is. In addition, the acceptance of NBS is expected to be related to the co-benefits provided to communities, otherwise known as the welfare-increasing aspects, such as health benefits and increased aesthetic value[6,30,32], or increased attractiveness of spaces. As for market acceptance, finding investors and developing business models for NBS may be challenging. However, the recreational functions offered by NBS could invite economic activities to the area by resulting in a cluster of shops, kiosks, and restaurants. Furthermore, green bonds, nature funds, and carbon credit markets may make NBS a viable business model.

From a methodological standpoint, each social acceptance dimension determines the population from which a research sample will be drawn. In accordance with the NBS in question, acceptance can be based on any or all three dimensions. Yet, as clarified further below, the four NBS under consideration in this research have either been fully implemented or are in the process of implementation. Hence, the local and regional planners have already accepted the projects, and that community acceptance is the most relevant dimension in the context of NBS considered in this research[19].

The theoretical model

Social acceptance implies that it is not only people's attitudes but also their behavior towards technology or policy that is positive. In the context of NBS, this means that people will be willing to visit and make use of the application in question and that they would not oppose or protest against NBS that has been proposed or implemented by planners. In order to infer current or predict future behavior, researchers may measure attitudes without explicitly discussing their connection to behavior. Similarly, they may typically account for how intentions to act may translate to behavior. There is, however, a dominant theory in the field of psychology that does account for these interactions: the theory of planned behavior[34].

The theory of planned behavior[34] suggests that attitudes influence the intention to behave, which in turn influences actual behavior. The theory further postulates that subjective (social) norms and perceived behavioral control also influence peoples' intentions to behave in a particular manner. In this context, attitudes refer to the degree to which the action is favorable or not. On the other hand, subjective norms are invisible social pressures or obligations that encourage or discourage specific actions and perceived behavioral control, which refers to the perceived ease or difficulty of carrying out specific behaviors.

Based on the theory of planned behavior, the first item we consider including in our model is attitudes. When explaining the acceptance of technology or intervention, two types of attitudes come into play: global attitude (i.e., attitudes towards the technology or intervention itself)[35] and attitudes towards a specific behavior (i.e., purchasing behavior, protesting, voting, etc.) in response to the availability or implementation of the technology. While we recognize the importance of understanding attitudes towards a specific behavior -which will, in turn, provide a prediction of the intention to perform that specific behavior-, we choose not to specify the type of attitude in this research. There are two main reasons why we opt to do so. First, when a type of attitude is specified, questions posed to a potential audience need to be very specific, and second, the responses would only inform specific behavioral intentions[36]. For instance, we would need to ask whether respondents would be willing to take a certain action related to a nature-based solution within a specific timeframe in a specific location. Consequently, measuring attitudes consistently in relation to a specific behavior would limit the generalizability of this framework to different socio-spatial contexts. Moreover, it would require that we limit the set of behaviors that can be studied. Considering general attitudes, instead, may provide greater value to policymakers in that it would allow them to understand the antecedents of various behaviors. Provided these findings, we start adding measures that directly influence general attitudes to build out our model. These measures include cognitions (i.e., perceived benefits, risks, and costs)[15,37,38]. In the context of NBS, costs may include financial costs associated with the re-naturalization process. Perceived risks may include safety hazards, and certain negative impacts associated with the implementation of NBS, such as increased traffic, and dust, among others. Benefits, on the other hand, encompass positive impacts on the region's climate and endemic species, regional economic development, and any benefits to family and friends from using the NBS[21]. We focus specifically on the perceived, salient cognitions because they have been shown to be more influential on behavior[39].

Next, we consider the two other factors that the theory of planned behavior suggests may impact the intention to behave: subjective norms and perceived behavioral control. We believe subjective norms apply to the NBS setting as there are some invisible social pressures to support projects that address climate change. However, we do not include perceived behavioral control in our proposed framework because focusing on general attitudes instead of behavior eliminates any difficulty associated with performing the behavior in question for this research (i.e., expressing an opinion by responding anonymously to a survey).

While the theory of planned behavior predicts behavior that results from thoughtful decision-making, it is increasingly being recognized that people often show automatic behavior, habitual behavior, or a behavior influenced directly by feelings. That is to say, adding extra predictive variables to our model that account for these observations may help increase the explanatory power of our acceptance model and ensure that our attitudinal measures are as representative of people's intentions and actual behavior as possible.

The first set of extra predictive variables we include in our model relates to feelings. Various psychological studies have pointed to the importance of theories on affect[40] in explaining attitudes[41,42] and following the theory of planned behavior, therefore indirectly the intention to behave. One study, in particular, has gone even further and suggested that affect can be as important as, if not more important, than cognitions[43]. More specifically, it has demonstrated that when cognitions and affect are aligned (i.e., both positive or negative), they exert almost equal influence on attitude, but when they contradict, affect has a stronger influence on attitudes when compared to cognitions. In line with these findings, we include affect in our model. Provided that both negative affect (feelings of stress, worry, anger, and fear) and positive affect (feelings such as joy, hope, satisfaction, pride, and calmness) are independent and significant elements in explaining the acceptance of technologies and policies[44,45], we add two separate variables for negative and positive affect in our model.

The second set of extra predictive variables we include in our model relates to personal norms. The psychological theory behind the inclusion of these variables is the norm activation theory[46,47]. The norm activation model suggests that individuals perform socially-desirable actions when they feel they are bounded by a moral obligation to do so. This is reflected in the factor of personal norms. Individuals develop personal norms when they are aware of the negative consequences of not performing pro-social behavior, and when they believe that they can play a critical role in addressing prevalent issues[47]. The outcome efficacy variable in our model accounts for the degree to which individuals may contribute to mitigating problems and is measured through an assessment of the extent to which individuals believe their

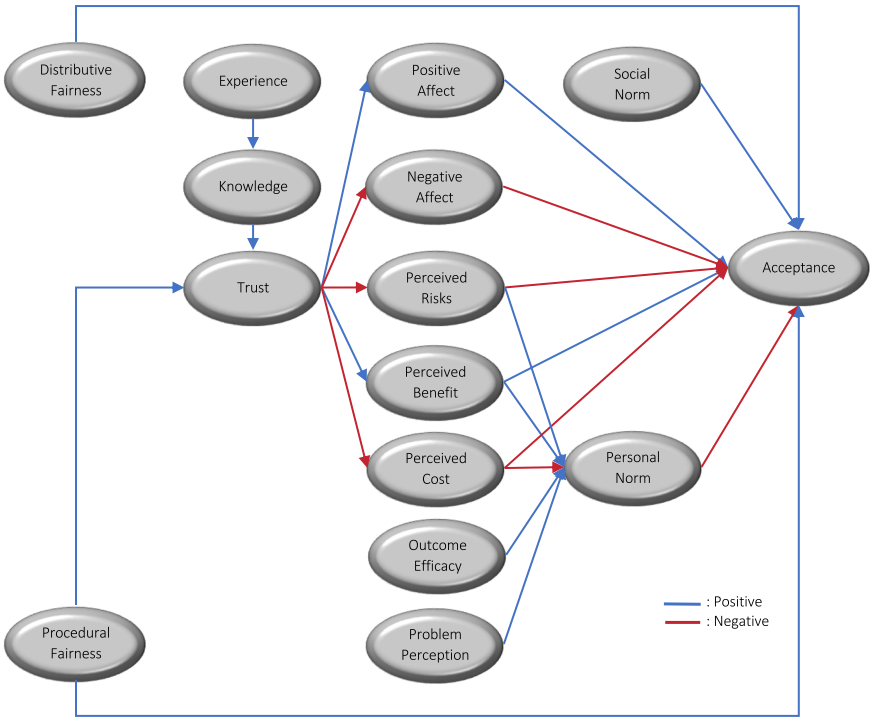

Fig. 1 The hypothesized model of the social acceptance of NBS. Arrows represent the direction of causality between the latent variables. The red and blue arrows represent negative and positive associations, respectively.

behavior in favor or against the NBS will be considered the implementation of the project. Related to the acceptance of NBS, awareness of adverse consequences (as reflected in the problem perception factor) refers to awareness of problems associated with climate change. We anticipate that individuals who recognize environmental damage as a result of climate change will be more inclined to support NBS, as these solutions are aimed at building resilience against climate change impacts.

In addition to the above factors that relate to the evaluation of NBS, there are others related to the way the solution is implemented that may influence acceptance. When the implementation process is considered, three key topics emerge as most important: by whom the solution is being implemented, the procedures involved in the implementation, and the region of impact. Below, we discuss these topics in detail.

When little is known about a technology or policy, the literature suggests that trust in actors who implement technologies or solutions serves as the foundation of the public's opinion[12,45,48–52]. Trust impacts attitudes by influencing how people weigh risks, benefits, and costs. The more individuals trust actors to participate in the development and implementation of projects, the more inclined they are to tolerate risks or uncertainties[13]. To represent this impact, we link trust to acceptance indirectly via perceived costs, risks, and benefits.

The notion of fairness is essential, particularly in the context of community acceptance. The two elements of fairness that are key to this study are procedural and distributive fairness[53–55]. Distributive fairness relates to the distribution of benefits, risks, and costs. As it is concerned with the implications of decisions at the community scale rather than at a personal level, distributive fairness is said to be more influential on the acceptance of technologies[56]. Procedural fairness, on the other hand, involves providing different actors with a voice in decision-making processes[54,57] and is an important consideration because it has the potential to improve the quality and legitimacy of decisions through building a platform for all actors to engage in the policy discussions[58]. Increased participation may also lead to superior outcomes with respect to environmental quality and other social targets by enhancing trust and credibility and strengthening the relationships among community leaders, government agencies, civil society representatives, and other stakeholders.

Knowledge is another factor that is essential in understanding the acceptance of new technologies or projects because it allows individuals to make sound judgments[59]. Knowledge can be developed either by information dissemination by program implementers or through experiences. For instance, in the context of NBS, individuals may visit the site in question or simply live in close proximity to the project. This will allow them to assess the gains and losses associated with a project and help them reach a more stable opinion about the NBS[39]. While some benefits of knowledge and experience will be visible in the short-term, increased knowledge and experience may also influence acceptance further in the project implementation timeline.

Combining the above interrelationships produces the comprehensive acceptance framework presented in Fig. 1, which is not limited to NBS, but can be adapted to quantify societal acceptance of other technologies and policies. The framework is a modified version of the renewable energy technology acceptance framework of Huijts et al.[13], adapted to reflect the unique characteristics and sensitivities associated with NBS. The hypothesized negative links are represented by red, and positive links are represented by blue arrows, respectively. In this study, for each NBS case, the significance of the relationships represented by arrows in the diagram below was simultaneously tested using the appropriate multivariate method.

General implementation strategy

This research proposes an empirical framework that can be employed by policymakers and industry representatives to understand attitudes toward NBS development in different social, spatial, and temporal contexts. There is a need for a framework providing common theoretical and methodological underpinnings to determine antecedent factors driving acceptability and enabling comparability. Increased emphasis on policy-relevant

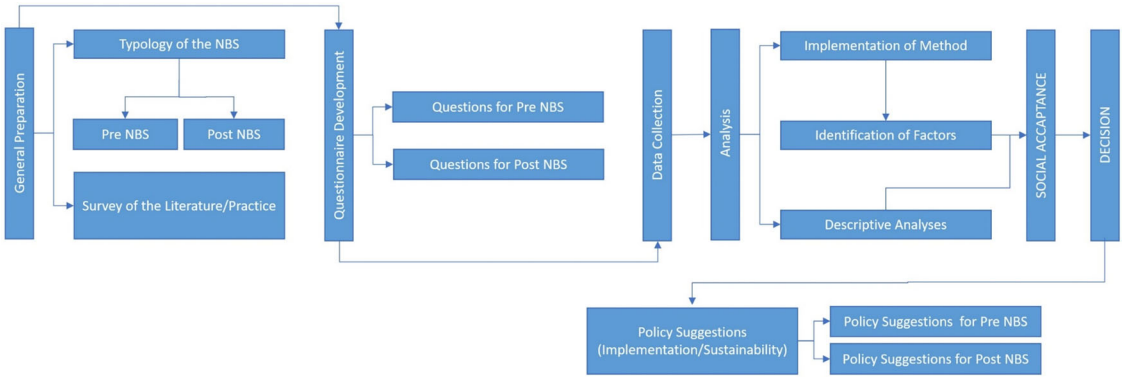

Fig. 2 A replicable and comparable decision-making framework for NBS. The framework illustrates how social acceptance is incorporated into the decision-making process and allows replicable and comparable results.

evidence over the recent decades has motivated the need for comparative, replicable, credible, and reliable research to signify policy development with rational decision-making. Anonymously tried and tested analytical methods convey the credibility and reliability of the evidence. A framework that opens the line for replicability and comparability will be a candidate for an evidence-based decision-making approach for NBS (See Fig. 2). Comparability must be ensured via process standardization and an accurate snapshot of all the phases involved in the analyses. The standardization is maintained by the framework process and by the common questions for any NBS type that rely on the three behavioral theories (see Supplementary Fig. 1). Figure 2 illustrates the empirical steps of social acceptance as a decision-support tool in implementing NBS[60]. The process starts with the opinions and ideas expressed through surveys and continues with the policy development and policy adjustment based on the survey data to implement socially acceptable NBS. The process is applicable for both pre and post -NBS implementations.

The framework development process starts with an extensive review of the social acceptance and NBS literature (Fig. 2). This informs the questionnaire development process by allowing the interested party to include values and challenges common to all NBS settings. An overview of situational factors follows this. These situational factors are identified either through field research or public consultations. Public consultations will allow different stakeholders to express their opinions and concerns and engage in decision-making processes. Conducting these consultations at the early stages, prior to survey development, will allow policymakers to include indicators that assess the significance of this stakeholder's concerns to other public members. It will also allow them to understand the influence these stakeholders may have on the evaluations of the public. For this research specifically, we refer to Nature4Cities[61], which identifies 75 NBS types and determines challenges related to each NBS type. Together with theoretical underpinnings and empirical evidence, we translate challenges into questions (see Supplementary Table 2). The questions are then modified for whether the NBS has already been implemented or is planned to be implemented.

The social acceptance drivers are determined after the survey is developed and fielded. In doing so, two types of assessments may be used. These assessments include descriptive analyses and the implementation of the method (PLS in this research) to identify factors that are important for social acceptance. Descriptive statistics and other fundamental statistical analyses help policymakers identify target groups with different opinions. The results of the analytical method (PLS, OLS, etc.) help policymakers identify the factors that are important to explaining attitudes. The insignificant factors could be removed from future surveys to make data collection easier. If factors are found to be significant, though, this means that concentrating on these factors could potentially change attitudes. Depending on the size of the direct or indirect effects represented by the coefficients, policymakers may prioritize certain psychological factors over others. One important note here is that policymakers should also account for the signs of these coefficients. If certain factors that were anticipated to be directly proportional are revealed to be inversely related, this would mean that something unique about that group is worth considering in policy designs.

The general implementation strategy is applied to four cases: METU Forest in Ankara, Turkey; Tisza River Bank in Szeged, Hungary; Forest Garden in Alcalá de Henares, Spain; and Quarries in Milan, Italy. This will help demonstrate how this generalizable framework may inform policymakers in various social, spatial, and temporal contexts.

PLS results are obtained in two stages: (1) evaluating model fitting, reliability, and validity of the measurement model; and (2) assessing the relationships between constructs in the model[62,63].

Measurement model results

We evaluate the measurement properties of the constructs by 'examining item loadings, composite reliabilities, and Cronbach alpha values'[63], which are reported in Supplementary Tables 3–6 for all four countries. Standardized factor loadings are recommended to be higher than 0.4[64,65]. Thus, we eliminated some of the items from further analysis as they did not meet the minimum standardized factor loadings (<0.4) recommended by Henseler et al.[66]. "Cronbach alpha values also indicate a high level of measurement reliability, as evidenced by values higher than 0.7"[67]. The lowest composite reliability values are 0.750, 0.792, 0.779, and 0.735 for Hungary, Italy, Spain, and Turkey samples, respectively, and all are above the recommended minimum of 0.7[68].

To assess construct validity, we examined convergent and discriminant validity[66,69]. The results are summarized in Supplementary Tables 7–10. Convergent validity is established when each measurement item has a strong correlation with the underlying theoretical construct. This is determined by examining the average variance extracted (AVE), which is used to assess how much variations on average can be explained by the construct under consideration in relation to the variation that measurement error has[69]. As Supplementary Table 3–6 illustrate, the lowest AVE values are 0.596, 0.520, 0.629, and 0.551 for Hungary, Italy, Spain, and Turkey samples, respectively, thus exceeding the recommended minimum of 0.5 for convergent validity[62,70,71]. The discriminant validity of constructs is determined by determining whether they share more variance with their measures than other constructs in the model[63]. For all four samples, the square roots of the AVEs (reported on the diagonals of the Supplementary Table 7–10) exceed the correlations with all other constructs (reported on off-diagonals in the Supplementary Table 7–10), thus satisfying

the discriminant validity[66,70]. We also checked if multicollinearity could be an issue. We found that the inner variance inflation factors (VIF) were less than 3 in all four samples, meeting the recommended maximum value of 5[68], indicating no multicollinearity.

We also checked for common method bias as the data were collected utilizing a single perceptual measurement instrument. Kock[69] states that if VIF values "are equal to or lower than 3.3, the model can be considered free of common method bias". As discussed above, all four samples meet this criterion. We also performed a single-factor[70] test (as in) for the purpose of identifying whether a single factor explains the majority of the covariance between variables. In four samples, an exploratory principal component factor analysis found that the first factor accounted for between 12 and 20.7 percent of the variance. This is less than the 50% threshold[72]. Therefore, we conclude that common method bias does not pose a threat in this research. After ensuring measurement reliability and validity, we proceed with the structural model.

Structural model results

In this research, a bootstrapping procedure with 1000 re-samples[62,73] is employed to calculate the t-statistics to test the hypothesized relationships. Table 1 illustrates the results of these hypothesis tests for all four samples. As the conceptual models slightly change depending on the case study, and we examined the implementation of different NBS, we did not pool data but reported the findings for each case study individually.

The results for Tisza River Bank illustrate (Fig. 3) that positive affect, negative affect, perceived cost, perceived risk, and perceived benefits played an important role in the relationship between trust and social acceptance in Tisza River Bank in Szeged, Hungary. The figure illustrates the significant factors only to be able to compare four cases. We discovered that trust was associated with positive affect ($\Upsilon = 0.529$, $p = 0.001$), which influenced social acceptance ($\Upsilon = 0.274$, $p = 0.001$) in the same direction. Trust was negatively associated with negative affect ($\Upsilon = -0.388$, $p = 0.001$), which influenced social acceptance in the opposite direction ($\Upsilon = -0.146$, $p = 0.001$). Lower levels of trust led to a higher perceived cost ($\Upsilon = -0.263$, $p = 0.001$) and a higher perceived risk ($\Upsilon = -0.271$, $p = 0.001$), which in turn decreased social acceptance ($\Upsilon = -0.146$, $p = 0.001$; $\Upsilon = -0.117$, $p = 0.05$). Trust, on the other hand, increased perceived benefits ($\Upsilon = 0.331$, $p = 0.001$), resulting in greater social acceptance ($\Upsilon = 0.119$, $p = 0.05$).

The above results highlight trust's importance in increasing social acceptance via different mechanisms: increasing positive affect and perceived benefits and decreasing negative affect, perceived costs, and perceived risks in the Szeged case. The importance of trust in Tisza River Bank's case is somewhat expected because the case represents a pre-implementation NBS example. In situations where the project implementation has not started or not been completed yet, reliance on the anticipated intentions and behaviors of key professional actors that are responsible for development (i.e., trust) becomes crucial primarily because the community does not possess enough knowledge or experience with the solution to make an informed decision[12,45,48–52]. Moreover, our findings confirm what has been suggested by the literature in terms of the channel through which trust impacts attitudes: it influences the way people weigh risks, benefits, and costs[13]. The substance of trust brings into question how trust in project implementers is formed. Based on our theoretical framework, the hypothesized antecedents of trust are experienced (which indirectly leads to trust via knowledge), and procedural fairness. However, our results suggest that in the case of Tisza River Bank procedural fairness is the primary determinant of trust. Although we found that more experience leads to more knowledge ($\Upsilon = 0.244$, $p = 0.001$), we were not able to confirm that knowledge is a predictor of trust ($\Upsilon = 0.041$, ns (not significant)), though it should be noted that this relationship could be different at the post-implementation stage as the local community may cultivate sufficient knowledge such that it influences their opinions about project implementers. In the case of procedural fairness, we found that a higher level of procedural fairness led to greater trust ($\Upsilon = 0.324$, $p = 0.001$). In addition, we found that procedural fairness not only had an indirect impact on social acceptance via trust but also had a direct effect on social acceptance ($\Upsilon = 0.145$, $p = 0.01$).

Another important dimension of fairness that is key to explaining attitudes towards Tisza River Bank is distributive fairness. We found that distributive fairness had a direct, positive impact on social acceptance ($\Upsilon = 0.136$, $p = 0.01$). That is to say, people must be informed and convinced about the fair distribution of the risks, costs, and benefits of Tisza River Bank. Again, as this is a pre-implementation NBS example, distributive fairness can be achieved by assessing the scale and degree of impact of each project during the planning phase and continuous knowledge sharing and communication about the potential impacts of the project throughout the project timeline. If any need for change is established during these interactions and if all risks, costs, and benefits are fairly distributed in the final stage, it is expected that the NBS will not encounter a strong and effective opposition from society.

As for other factors of consideration, based on our review of the literature on social acceptance, we had predicted five factors to influence personal norm, and therefore indirectly acceptance. Out of the five antecedents, only perceived benefits and problem perception had a positive association with personal norms ($\Upsilon = 0.296$, $p = 0.001$; $\Upsilon = 0.223$, $p = 0.001$), and perceived cost, perceived risk, and outcome efficacy had no impact on personal norms ($\Upsilon = -0.026$, ns; $\Upsilon = -0.039$, ns; $\Upsilon = 0.004$, ns). However, the impact of personal norms on social acceptance was not significant ($\Upsilon = 0.064$, ns). Similarly, we found no support for the hypothesized positive link between social norms and social acceptance ($\Upsilon = 0.004$, ns). We believe that the stage of implementation explains the insignificance of the relationship between personal norms and acceptance as well as that between social norms and acceptance. For personal norms, as local communities have not had any chance to visit the project site, it is anticipated that they would not have a feeling of moral obligation to support or oppose the solution. For social norms on the other hand, again since the project is not established, it is unlikely that there will be any social pressure that would encourage support for the nature-based solution.

The results for the Quarries in Milan (Fig. 4) indicate that trust was positively associated with positive affect and perceived benefits ($\Upsilon = 0.367$, p = 0.001; $\Upsilon = 0.288$, $p = 0.001$); and negatively associated with negative affect and perceived risks ($\Upsilon = -0.301$, $p = 0.001$; $\Upsilon = -0.222$, $p = 0.01$). These associations translated similarly to acceptance. However, perceived benefits also influenced acceptance indirectly through the personal norms. Similarly, perceived risks, costs and outcome efficacy influenced acceptance through creating feelings of moral obligation to support or oppose the Quarries in Milan.

Again, looking at the determinants of trust, we confirmed that participation in decision processes (i.e., procedural fairness) was a key driver ($\Upsilon = 0.138$, $p = 0.1$). Although we found that more experience led to more knowledge, we could not confirm that knowledge was a predictor of trust. In contrast to the Szeged, Hungary sample, in Milan, Italy, procedural fairness indirectly impacted social acceptance via trust but did not affect social acceptance directly. Interestingly, in comparison to the Hungary sample, distributive fairness did not influence social acceptance either. We had previously discussed some strategies that could help build procedural fairness. Hence, we will not repeat those

Table 1. Summary of findings.

Independent variables	Dependent variables	Tisza River Bank Path coefficient	T stat	*P* value	Quarries Path coefficient	T stat	*P* value	Forest Garden Path coefficient	T stat	*P* value	METU Forest Path coefficient	T stat	*P* value
Impact on Social Acceptance													
Positive affect	Social acceptance	0.274	4755	0.001	0.161	2390	0.05	0.177	1875	0.10	0.076	1254	n.s.
Negative affect	Social acceptance	−0.146	2710	0.01	−0.205	3609	0.001	−0.030	0.673	n.s.	0.014	0.355	n.s.
Perceived cost	Social acceptance	−0.146	3448	0.001	0.001	0.033	n.s.	0.087	1847	0.10	−0.044	1084	n.s.
Perceived risk	Social acceptance	−0.117	2178	0.05	0.026	0.379	n.s.	−0.005	0.082	n.s.	-0.162	2713	0.01
Perceived benefits	Social acceptance	0.119	2098	0.05	0.333	4903	0.001	0.421	3815	0.001	0.613	8668	0.001
Distributive fairness	Social acceptance	0.136	3141	0.01	0.029	0.594	n.s.	−0.005	0.104	n.s.	−0.022	0.565	n.s.
Procedural fairness	Social acceptance	0.145	3027	0.01	0.041	1056	n.s.	0.107	1753	0.10			
Social norm	Social acceptance	0.064	1520	n.s.	0.127	1647	0.10	0.083	0.940	n.s.			
Personal norm	Social acceptance	0.068	1408	n.s.	0.170	1972	0.05	0.225	3058	0.01			
Problem perception	Social acceptance										0.087	1837	0.10
Outcome efficacy	Social acceptance										0.050	1530	n.s.
Impact on Personal Norm													
Perceived cost	Personal norm	−0.026	0.416	n.s.	−0.054	0.925	n.s.	−0.052	0.653	n.s.			
Perceived risk	Personal norm	−0.039	0.620	n.s.	−0.230	3281	0.001	−0.128	1758	0.10			
Perceived benefits	Personal norm	0.296	3988	0.001	0.308	4042	0.001	0.495	7112	0.001			
Problem perception	Personal norm	0.223	3471	0.001	0.161	3204	0.001	−0.013	0.233	n.s.			
Outcome efficacy	Personal norm	0.004	0.052	n.s.	0.095	1857	0.10	0.035	0.524	n.s.			
Outcomes of Trust													
Trust	Positive affect	0.529	10567	0.001	0.367	4765	0.001	0.442	5389	0.001	0.326	6069	0.001
Trust	Negative affect	−0.388	6972	0.001	−0.301	4373	0.001	−0.147	1733	0.10	−0.124	1666	0.10
Trust	Perceived cost	−0.263	4502	0.001	0.126	1563	n.s.	−0.312	2929	0.01	0.048	0.602	n.s.
Trust	Perceived risk	−0.271	4164	0.001	−0.222	2857	0.01	−0.198	2044	0.05	−0.209	3219	0.001
Trust	Perceived benefits	0.331	4821	0.001	0.288	4066	0.001	0.364	4200	0.001	0.366	6283	0.001
Determinants of Trust													
Experience	Knowledge	0.244	4602	0.001	0.392	8016	0.001	0.195	2987	0.01	0.284	2714	0.01
Knowledge	Trust	0.041	0.566	n.s.	0.041	1000	n.s.	0.405	5115	0.001	0.308	5612	0.001
Procedural fairness	Trust	0.324	5308	0.001	0.138	1867	0.10	0.248	2884	0.01	0.223	4051	0.001

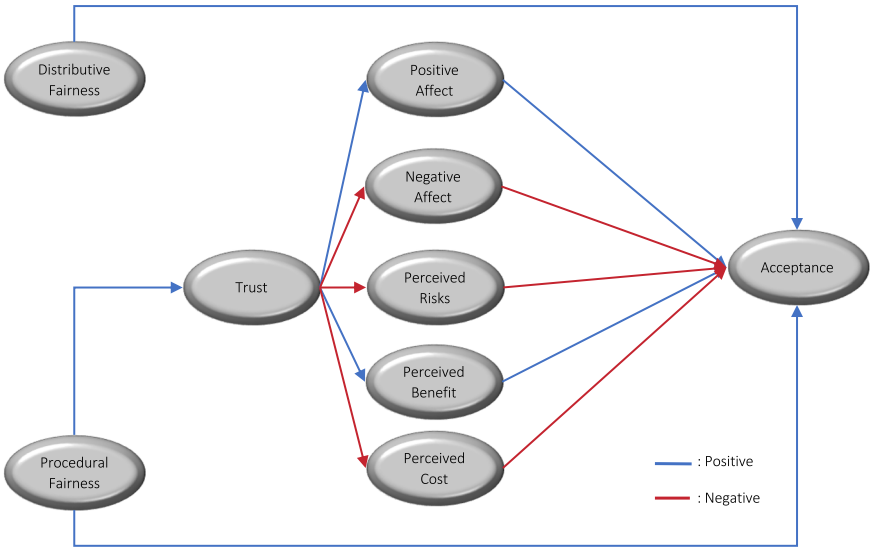

Fig. 3 Structural model results for the social acceptance of Tisza River Bank in Szeged, Hungary. Insignificant variables are dropped from the theoretical model. Arrows represent the direction of causality between the latent variables. The red and blue arrows represent negative and positive associations, respectively.

recommendations here. Rather, we will discuss strategies that are already being implemented by the decision-makers in Milan. Prior to initiating the re-naturalization process of the quarries, the Metropolitan City of Milan (CMM) initiated a participation process to design a new Quarry Plan. Several key stakeholders, including but not limited to municipalities, park authorities, civil society, and environmental protection organizations helped formulate this new plan. Another important note here is that there are 36 Quarries in Milan, and at the time of this research, environmental recovery is nearly finished in some but starting in others. This means that this step-by-step participatory process may have served as a learning experience for CMM. It allowed them to use the feedback they received from the first projects they worked on to ameliorate the design of the remaining quarries. Moreover, provided the findings presented in Fig. 4, it is likely that this approach helped further develop trust in implementers, which could have in turn potentially resulted in greater acceptance of projects that are yet to be fully implemented.

In Alcalà de Henares, all five hypothesized outcomes of trust were supported: positive affect and perceived benefits were positively associated with trust, whereas negative affect, perceived cost, and perceived risk were negatively associated (Fig. 5). However, only positive affect, perceived cost, and perceived benefits had a significant impact on social acceptance; path coefficients for negative affect and perceived risk were not significant.

Regarding the determinants of trust, similar to the previous cases of Szeged and Milan, procedural fairness emerged as an important factor. As in the case of Szeged, procedural fairness influenced the acceptance of the Forest Garden both directly and indirectly (through trust). As the citizens of Alcalà de Henares, Spain, have already had the opportunity to interact with the city council in charge of the implementation of the Forest Garden and learn about the solution in question, it is not unusual that inclusion in decision making has emerged as an important for this particular case.

Unlike the cases previously explored in this paper, though, we found that more experience led to more knowledge, which led to greater trust in the implementers of the nature-based solution in the Forest Garden. That is to say, if policymakers are to achieve greater acceptance of the solution in Alcalà de Henares, they will first need to ensure that citizens are able to visit the site (either in person or virtually), experience it, and observe similar applications. The knowledge they develop through these interactions will allow individuals to objectively evaluate the risks and benefits of the Forest Garden. However, knowledge is not solely developed through experiences, Project implementers may also help inform the public by sharing Forest Garden or NBS-related books, social media content, or pamphlets that include information about the improvements, preservation, and protection of the Forest Garden. Sharing this information will likely influence the following measures of the trust construct: perceived reliability, intentions, competence of implementers, tendency to disclose information, transparency in planning and implementation, and thus indirectly influence social acceptance.

Finally, we found that personal norm was significantly associated with social acceptance of the nature-based solution in Spain. However, out of the five antecedents of the personal norm, only two, namely perceived risk and perceived benefits, were associated with the personal norm, whereas perceived cost, problem perception, and outcome efficacy had no effect. Although personal norm was a significant predictor of social acceptance, social norm had no impact. The results highlight the role of perceived risk and perceived benefits in increasing personal norms, which in turn increase social acceptance.

The results of METU Forest in Ankara indicates that trust was positively associated with positive affect and perceived benefits, as seen in Fig. 6. Yet, only perceived benefits positively affected social acceptance. The path coefficient for the positive affect was not significant. Similarly, we found that trust was negatively associated with negative affect and perceived risk; however, only perceived risk had a negative impact on social acceptance, and the path coefficient for negative affect was not significant. This is indeed an exciting finding because previous research on the impact of cognitions and affect on attitudes had demonstrated that, when compared to cognitions, affect has an equal, if not more substantial, impact on attitudes[43]. Contrarily, this specific case has demonstrated the exact opposite relationship (i.e., cognitions are more relevant to explaining acceptance). Instead, the analysis confirms that the community weighs the risks and benefits and founds their opinions on the comparative value of these factors.

According to our analysis, another important factor explaining acceptance indirectly was trust. We discerned that more experience led to more knowledge, resulting in greater trust. In this case, the causal interactions indicate, one key strategy for

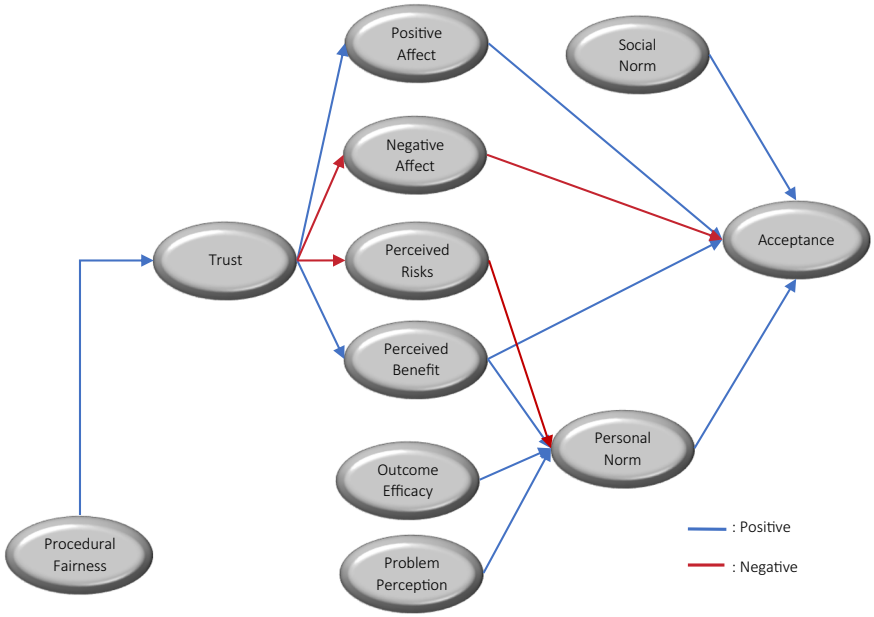

Fig. 4 Structural model results for the social acceptance of Quarries in Milan, Italy. Insignificant variables are dropped from the theoretical model. Arrows represent the direction of causality between the latent variables. The red and blue arrows represent negative and positive associations, respectively.

improving social acceptance in Ankara, Turkey could be to engage citizens in activities at METU Forest. This could in turn help develop more knowledge about the ecosystem and encourage Ankara residents to actively support and protect this nature-based solution. METU forest and the lake within creates many possibilities for community engagement. Social and cultural events, sports activities, and controlled periodic educational visits or field trips about the plant and animal life in the METU Forest ecosystem could address the need for increased interaction with the solution. METU Forest is man-made, and the students, faculty, staff, and alumni of the university visit and plant trees in the forest on a regular basis. Nevertheless, currently, the forest is only easily accessible to those affiliated with the university. The general public has limited access to a section of the nature-based solution, that is, the forest surrounding lake Eymir. The university may be able to facilitate access to the forest to increase citizen exposure.

Another factor that has the potential to contribute to trust and indirectly to acceptance is procedural fairness. Similar to all cases included in this paper, in the case of METU Forest, we concluded that procedural fairness has a positive impact on trust, therefore indirectly on social acceptance. In this respect, it should be noted that given that access to the forest is limited, the decision-making process surrounding the application does not involve a variety of stakeholders either. While it is unlikely that this will change substantially in the near future, were some parts of the forest to be opened to the public, it would be beneficial to include Ankara residents in the decision processes that will have an impact on the sustainability of the forest. Residents may be able to share their thoughts on forest expansion, potential uses of the forest, community events, among others.

DISCUSSIONS

It is widely accepted that social acceptance is essential for effective policy implementation and wider technology adoption. Yet, it has been challenging to quantify social acceptance and determine its drivers since it is not a readily observable factor. This study presents a systematic way to approach this problem. Applying our systematic framework to four different NBS in four different European cities has shown that drivers of social acceptance can vary across NBS and countries. Although there is no one-size-fits-all policy to improve public acceptance of NBS, due to differences in NBS types, sizes, locations, and in cultural and political landscapes, it becomes evident that the determination of social acceptance and tailored decision-making is vital for the sustainability of NBS. Understanding the risk and benefits of an NBS and developing personal norms related to the environment will have consequences in favor of improving climate resilience in cities. Overall, the results indicate that procedural and distributive fairness, perceived risks, costs and benefits, knowledge, experience, and personal norms are the critical factors affecting the social acceptance of NBS, either directly or indirectly.

The findings open a venue for formulating powerful and tailored strategies with a destination for the sustainability of NBS for each case independently. The flow of significant impact, for instance, goes from experience to knowledge in the METU Forest and Forest Garden. Given that these two cases represent post-implementation NBS examples, it is expected that experience and knowledge will play a key role in the formation of attitudes. In such cases, participation in events and activities taking place in community-wide NBS must be inclusive of all citizens, particularly those who have not experienced the NBS and those who have not taken part in the decision processes. NBS provides a variety of opportunities for citizens to engage with the community, such as sports activities, social and cultural events, conferences, and other activities that allow citizens to gain knowledge about the nature-based solution as well as experience and form place-attachment, resulting in increased acceptability. In the METU case, for example, all activities are typically carried out by students, alumni, administrative staff, and academics. However, to develop favorable attitudes towards the NBS and to establish a sense of trust in the authorities, all citizens should be allowed to participate in the activities, events, and decision-making processes that will affect the sustainability of the forest. The inclusion of the general public in decision-making has emerged as a strategy applicable not only to pre-implementation NBS, but also to post-implementation NBS. Local communities desire to be part of decisions that impact their well-being. At the pre-implementation stage, they want to provide feedback so that the project will provide greater benefits and fewer risks. At the post-implementation stage, they want to share

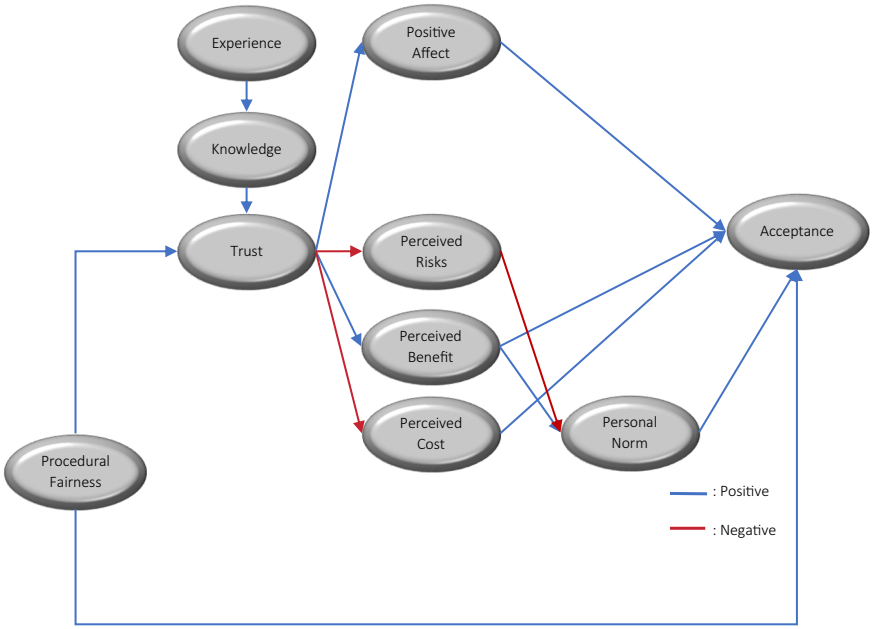

Fig. 5 Structural model results for the social acceptance of Forest Garden in Alcalá de Henares, Spain. Insignificant variables are dropped from the theoretical model. Arrows represent the direction of causality between the latent variables. The red and blue arrows represent negative and positive associations, respectively.

their thoughts on how to sustain the NBS in question. The initiation of this dialogue will particularly be important in cases where acceptance is strongly influenced by both procedural and distributive fairness, as in Szeged and Milan.

Citizens' engagement in the decision-making process could be through invitations to town halls, meetings or convenings, opinion polls, voting on proposed improvements or policy changes, or feedback forms. Opening these avenues for communication will achieve three goals simultaneously: (1) it will allow various stakeholders to raise their legitimate concerns and allow policy-makers and project implementers to continuously improve their designs; (2) it will facilitate knowledge sharing and knowledge improvement about global challenges, such as air pollution, climate change, global temperatures, and local environmental issues, that will in turn help communicate the value proposition of NBS; and (3) it will establish belief in the decision-makers' ability to effectively account for the values, concerns, and opinions of the public, and therefore allow citizens to better assess the costs, risks, and benefits associated with the NBS.

Going back to the literature, one might recall that fairness of procedures relates to the consideration of opinions. In order to achieve greater procedural fairness, project implementers in Szeged must ensure that individuals from different groups all feel that their opinions are sufficiently regarded in the planning and implementation of projects[57]. Actualizing this goal involves the inclusion of a sufficiently broad and diverse group of participants, which can be achieved through the identification of clusters within society that have differential viewpoints. Once these stakeholders are identified, they may be invited to participate in strategic planning meetings or feedback sessions or may be asked to express their opinions by voting for their preferred options. Establishing these channels for communication between project implementers and various stakeholders may also reveal the areas where greater transparency is needed. Policy-makers may then use targeted information campaigns to communicate the best available information to relevant groups. Information may include typed or visual aids as well as on-site visits. Nonetheless, as actual visits are not possible for a pre-implementation NBS project like Tisza River Bank, virtual tours, and posts on social media may be more suitable options to improve communication.

Although this study focuses on the resilience of urban areas to climate change, a similar approach can be used to assess the acceptance of mitigation strategies and low-carbon technologies. The results cannot be generalizable to the entire population of the country, and we do not have such an expectation. We focus on community acceptance, and the general public acceptance and community acceptance can vary greatly. It is sufficient to have generalizability of the samples to the local communities. We randomly sampled around the NBS using a zoning procedure to ensure that our respondents are people who are (or will be) exposed to the NBS. It would be fruitful to account for group perception formation dynamics in addition to individual perceptions in future social acceptance studies.

METHODS

The partial least square method

This study approaches the social acceptance of NBS by measuring latent factors and testing links provided in Fig. 1. The previous literature[74] suggest utilizing either an experiment or a case study in testing relationships among latent constructs. Given the complexity of the model and the number of hypotheses considered in this research, we utilize the partial least squares (PLS) method by using SmartPLS 3.0M2 software for calculations. In such cases, a sample size of less than 100 is regarded as small, a sample size of 100 to 200 is medium, and a sample size of more than 200 is large[75]. Given the difficulty in gathering data through surveys, such as low response rates and missing responses[76,77], we aimed for a sample size of 200-300 people for each case study. During the study, a written consent was obtained from each respondent. The details of the research design are given in the Supplementary Methods.

We used the partial least squares (PLS) method to test our hypotheses. The PLS technique is a component-based structural equation modeling (SEM) technique that uses an iterative estimation algorithm consisting of a series of OLS regression analyses[62,78]. This method aims to maximize the explained

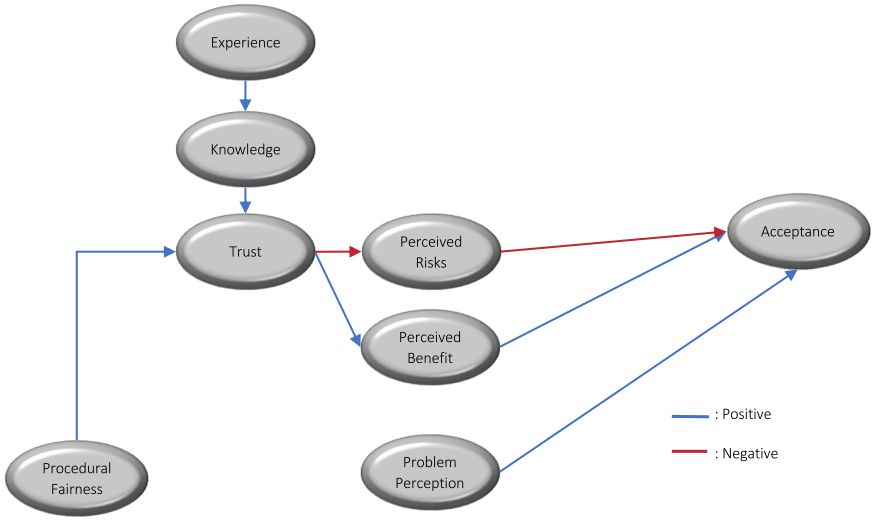

Fig. 6 Structural model results for the social acceptance of METU Forest in Ankara, Turkey. Insignificant variables are dropped from the theoretical model. Arrows represent the direction of causality between the latent variables. The red and blue arrows represent negative and positive associations, respectively.

variance of endogenous constructs[62,78]. Covariance-based structural equation modeling requires multivariate normality, which is not the case with PLS. Contrarily, PLS places minimum requirements on measurement levels and can, therefore, handle both single and multiple item measures. This makes it more suitable for small samples[62,68]. It employs a nonparametric bootstrap method, in which subsamples are generated from the original data set until a large number of random subsamples are generated. It works well with complex models, offers a higher degree of statistical power, and avoids two common issues with covariance-based SEM[66,70]. PLS was the best choice for this study because of the complexity of our conceptual model and the use of single and multiple-item measures.

DATA AVAILABILITY

All data supporting the findings of this study are available at: https://doi.org/10.5281/zenodo.7642654

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AUTHORS CONTRIBUTIONS

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COMPETING INTERESTS

The authors declare no competing interests.

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