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# Pavement sustainability: a tripartite analysis of natural stone pavements in Hanoi, Vietnam

**Dinh-Phuoc Le\*, Minh-Huyen Do and Ngoc-Oanh T. Duong**

Faculty of Urban and Rural Planning, Hanoi Architectural University, Hanoi 100000, Vietnam

\* Corresponding author's e-mail: [phuocld@hau.edu.vn](mailto:phuocld@hau.edu.vn)

**Abstract.** As a basic component of the city's structure and, particularly, an integral part of the transportation infrastructure, pavements fundamentally contribute to the city's achievement of sustainability goals. This paper examines the environmental, societal, and economic impacts of using natural stone for the pavement to pursue an ideal image of Green-Clean-Beautiful city by the government in the burgeoning city of Hanoi, Vietnam. It addresses the urgent question of whether natural stone is a sustainable paving material in a tropical climate under the impacts of climate change. By analysing the published contents of the official press, supported by data and information gathered from interviews with key experts, stakeholders, and urban residents, this paper argues that the actual impacts of natural stone use for pavements on the environment, economy, and society are strongly negative, compared to the positivity initially perceived in Hanoi's scheme of changing the pavement facelift. It shows that by overemphasising appearance and imagined nationalism values when selecting natural stone, Hanoi government shows a slow progress in improving and balancing functional, social, environmental, and economic dimensions. The paper is significant in contributing to knowledge on pavement sustainability and sustainable materials while shedding light on the challenges of applying these theoretical perspectives into real-life practice.

## 1. Introduction

The existence of humankind is at stake, as the impacts of climate change are ubiquitous. The continuous increases in global temperature worsened by sea level rise lead to more frequent and deadly catastrophes, including extreme heat waves, severe droughts, flooding, typhoons, and tsunamis. The damage and loss caused by such events are unbearable, which often casts a shadow over the impacted community for a long period, whether from a small residential area to a city or a metropolitan area. However, the intensity and severity of climate change impacts are not the same in different parts of the world. This is due to the geographical and developmental differences, including natural conditions, climatic patterns, topographic characterisation, and particularly political and socio-economic development strategies, policies, and projects whose operations contribute to either positive or negative climate change impacts.

Vietnam, a tropical country located in the southeast part of the Asian continent, is extremely vulnerable to the impacts of climate change. This is due to its extensive coastline, which is adjacent to a number of river deltas in the western part, and the eastern highlands, which account for three-quarters of the whole country area and have a poor capacity for water retention and are susceptible to landslides



and severe erosion. To make matters worse, the country's vulnerability to climate change seems to be further exposed by many of the government's developmental projects. One of which is the urban refurbishment and upgrade programs for rapid urbanisation. Most controversial scheme is the changing of pavements' facelift (*thay áo vỉa hè*) in the capital, historical city of Hanoi, commencing in 2010.

The association between the pavement sector, as an integral part of transportation, and climate change is clear. Globally, with a totality of above 16.3 million kilometres of pavement infrastructure, pavement material production and related industrial processes are accountable for about 21% of global greenhouse gas emissions, which are the main polluting sources causing climate change. The intention and approach that any government, institute, and organisation take towards the pavement will either increase or reduce these emissions, thereby contributing directly to climate change impacts mitigation or amplification. However, the impacts on the environment of the pavement sector are just one part of the whole story. According to pavement sustainability, economic and societal impacts are also vital because economic limitations and societal needs make it harder to achieve pavement sustainability goals aimed at improving the environment-economy-society system [1].

The aim of this paper is to examine the impacts on the environment, economy, and society of the scheme of pavement rehabilitation in Hanoi by employing the conceptual framework of pavement sustainability. The paper examines these environmental, economic, and societal impacts during four essential stages of a pavement's life cycle, including the production of natural stone slabs, construction, use, and maintenance of stone pavements. Data from secondary sources including journals and the official press, supported by primary data gathered from interviews with key experts, stakeholders, and urban residents, is used as the basis for the analysis and discussion.

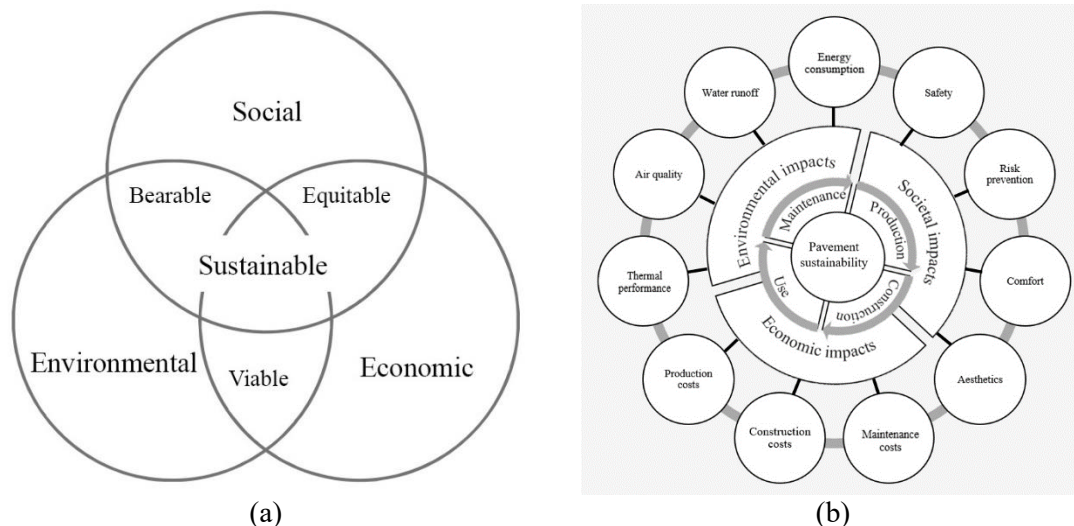
## 2. Pavement sustainability - conceptual framework

"Sustainability" is an elusive and vague term that has been employed extensively in many fields. The term is often used interchangeably with sustainable development (first appearing in the World Charter for Nature [2]), which is later defined according to the Commission on Environment and Development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [3]. This type of development is possible only through the balancing of three fundamental concerns: environment, economy, and society, which are represented in a tripartite modal or overlapping sphere (see Figure 1a). The three-pillar model is applicable in all disciplines and systems without any exception. When it comes to transportation infrastructure, or particularly the pavement, sustainability refers to the environmental, economic, and societal impacts of this specific infrastructure throughout its life cycle, which includes the production of the material, the construction, the use, and the maintenance or preservation [1, 4].

Pavement sustainability objectives are ambitious but necessary and aim to simultaneously raise awareness of environmental protection and compliance, economic adaptation and limitations, and emerging societal needs and demands at all stages of the pavement life cycle. The ultimate goal is the creation of sustainable pavements that are safe, efficient, cost-effective, and environmentally friendly, meeting the needs of present users without compromising the opportunities of future generations to meet the same needs. To accomplish these overall objectives as well as the final goal, several radical proposals have been endorsed, including the shift towards renewable sources from the exploitation and exhaustion of non-renewable natural resources, and the investments in advanced technologies and technique to manufacture innovative materials with better qualities that can eliminate or deal with the impacts of climate change, and improve the pavement's performance and quality. However, the progress has appeared to be slow and unsatisfactory, with natural resources still being exhausted while investments in producing innovative materials are found to be basic priorities [1].

Measures and guidelines for the accomplishment of pavement sustainability goals have been introduced to focus particularly on environmental indicators in response to climate change impacts, including the preservation of ecosystems, energy consumption, thermal performance or urban heat island effects [5, 6], GHG emissions, water runoff, noise levels, and air quality in order to achieve pavement sustainability goals [4]. Simultaneously, it is equally important to consider the expenses and

costs associated with all life cycle phases, such as the production costs of raw materials, the construction and maintenance costs of the pavement, and the recycling costs of waste materials [7], which often cover the expenditure on labour, equipment, transportation, and energy [4]. With regard to the societal dimension, these indicators often include concerns for user safety and comfort, health improvement, risk prevention, pavement characteristics, and aesthetics [1, 4, 8].



**Figure 1.** (a) Sustainability triple-bottom line [1], (b) Pavement sustainability integrating lifecycle analysis conceptual framework.

The benefits as well as impacts of pavements on the environment, economy, and society are significant but often overlooked by some governments, stakeholders, and a portion of the public. Besides one of their key practical roles and functions as a basic transportation infrastructure serving road users, transportation movements, and technical establishment, pavements contribute overtly and covertly to economic, environmental, and societal values, all of which lie at the core of a healthy, balanced system. Without a proper, systematic approach to pavement development, environmental, economic, and societal well-being and stability are certainly at risk. In this respect, sustainability development with a holistic approach that provides a general framework of analysis and reference concerning three dimensions: environment, economy, and society, is vital. However, even with the general framework defined and well-practiced, the endorsement and practices of pavement sustainability are contextual and value-laden, which are highly influenced by a variety of factors. The context and situation in which pavement sustainability is endorsed are specific to the location, climatic characteristics, available resources, governmental policies, institutional and organizational goals, and many other conditions that often hamper the endorsement [4]. It can be counterproductive to introduce preconceived sustainable features into a decision-making process without first thoroughly understanding the local context.

### 3. The context and outline of Hanoi's pavement rehabilitation for 'Green, Clean and Beautiful'

Since August 2010, the year that marked 1000 years of development after the emancipation from the invaders to the north, Hanoi has paid attention to the pavement's conditions and values. To prepare for the milestone anniversary, the government of the Socialist Republic of Vietnam launched an extensive campaign instilling the responsibility incumbent upon institutes, organizations, and every citizen to make Hanoi clean and beautiful. An online article was written by Pham Quang Nghi, a member of the Ministry of Politics and the Secretary of both the Communist Party and Hanoi City Committee, for the Communist Party of Vietnam to urge all Vietnamese, and Hanoians specifically, to promote 1000-year traditions of civilisation and heroism, building an even more rich, beautiful, civilised, and modern city

in Hanoi, the capital [9]. The notion of being clean, beautiful, and modern was picked up by other government press, and the association with it was the pavement. Cleaning and beautifying the pavement were the first priorities, as the more beautiful and clean the pavements, the more civilised and modern the city. One article at that time expressed that ‘the streets [often with their pavements in mind] are the face of the city’ from which ‘one can evaluate the intellectual level of the resident population’ (Kim, cited in [10, p.622]).

With the ideology of pavement beautification and civilisation ever since the 1000-year celebration, there have been four times the Hanoi government has refurbished the pavement (*bốn cuộc đại tu vỉa hè*). It has been decided since then that natural stone, including limestone and granite stone, is the most suitable paving material that represents the idea of cleanliness and beautifulness and seems to be compliant with the Communist Party’s framing of collectivism, modernity associated with a standard of living, and a nationalist revolutionary history featuring endurance and patriotism [10]. Gradually but steadily, natural stone slabs have replaced concrete and brick paving blocks. At first, square limestone slabs with 60 centimeters on each side and 50 kilograms in weight were used to pave the important squares and the sidewalks of the roads and streets in the city centre, especially the ones that connect to the city core—Hoang Kiem Lake. This initial commitment was to specifically serve the anniversary event in 2010, and it seems to be well supported by the Hanoian because of the significance of this event as well as the festive atmosphere, in which people tend to ignore any negative association.

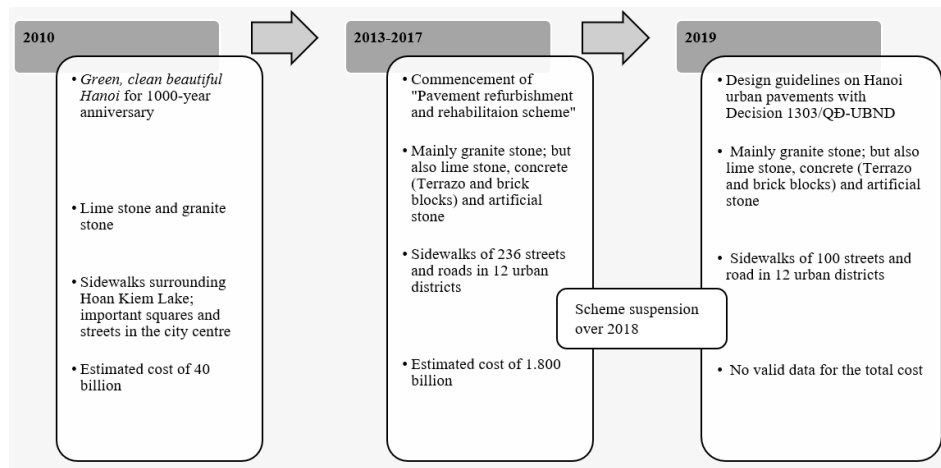


**Figure 2.** Dilemma reality for Hanoi pavement: (a) Multiple activities on a torn pavement, (b) A popular scene with cracked and broken stone pavements.

In 2013, the Hanoi government announced the second plan to change the city pavement’s facelift with the declaration of “The scheme of pavement refurbishment and rehabilitation for Hanoi to 2020” (*Đề án cải tạo chỉnh trang hệ phố Hà Nội đến năm 2020*). The target set for the rehabilitation work is more than 900 streets, and there are two phases in the implementation: one from 2013 to 2015 and another from 2016 to 2020. Besides the overarching goals, the specific justification for this scheme is to aestheticize and homogenise certain pavements within the city in the first phase, and all in the later stage, making them more beautiful, harmonious, and safe for the pedestrians [11]. Accordingly, about five streets of each district (10 districts in total) were selected for the rehabilitating work, and this time, granite stone was chosen instead of limestone, partly due to the expensive price of the later. It is worth noting that some streets, such as Dinh Tien Hoang, which were previously installed with limestone stone slabs during the 1000-year anniversary, have had their pavements refaced. It is also noticeable that, unlike the first commitment in 2010, this time, negative reactions and criticism by the public have been piled up on multiple platforms as a result of the ambitious but lackadaisical research scheme and its infamous implementation since 2014. Although being advertised to have a long lifespan up to 70 years, severe cracks and broken pieces of natural stone were found in almost all newly paved pavements (Figure 2a, b), as were the related issues of user safety, digging-burying uncertainties and disruptions,



waste, and corruption [12-15]. The Hanoi government and local authorities, the investors, and contractors acknowledged the mistakes and their lack of experience while simultaneously blaming these also on the lack of consistent guidance and regulation, which led to a pause in 2017 for investigation (see Figure 3).

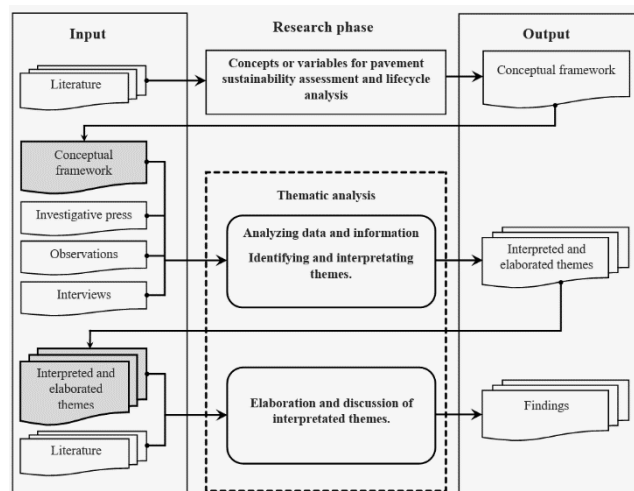


**Figure 3.** Hanoi pavement refurbishment timeframe

After a one-year suspension, the second phase of the scheme started again in early 2019 after the results of the investigation were released in 2018 (Announcement 675/TBKL-TTTP). The target for this year alone was about 100 streets. This time, the Hanoi government issued Decision 1303/QĐ-UBND to provide design guidelines on Hanoi urban pavements. Despite the detailed guidelines on how to design and install the stone slabs, the same things as in the first stage happened. Stone slabs continued to be broken or marked with multiple cracks. An investigation is currently under way to, again, identify the causes of this particular issue, and so far, a number of wrongdoings have been found in the design, construction, usage, and maintenance of pavement implementation, with a number of scapegoats being made [16-18]. Even though the causes are quite obvious—even a lay person without knowledge about natural stone can see and explain the causes, as many experts in the field mentioned [14, 16]—and despite criticism by experts and the public, the scheme is continuously carried out. Up to the present, there have been about 255 streets among all of the city's districts with their pavements being replaced with granite stone slabs, and hundreds of billions of VND have already been spent on such a scheme.

#### 4. Methods and materials

This is a qualitative work in nature, as the data was obtained qualitatively from the secondary and primary sources. Secondary data from various journals and the official press serves as the basis for the analysis and discussion. First, a framework for analysis was established out of the themes and variables that emerged from the literature review in the domains of sustainable development, pavement sustainability, and sustainable paving materials (see Figure 1b). Based on this established framework, in the second phase, the authors extensively examine the contents that have been published since 2010 in the Vietnamese official press by searching keywords such as "*lát đá vỉa hè*" and "*vỉa hè Hà Nội*". The results include online newspapers from *dantri.vn*, *vnexpress.net*, *vietnamnet.vn*, *hanoimoi.vn*, *quochoitv.vn*, *baogiaothong.vn*, *vov.vn*, *tuoitre.vn*, *thanhnien.vn*, *tienphong.vn*, and national television news and investigative podcasts (*viv.vn*). Information and data acquired from these online sources then were used as a basis for interviews with key experts, stakeholders, pedestrians, and residents. All of the emerging themes were further supplemented by information from articles, reports, and other electronic sources. These themes then were elaborated in the finding and analysis section (see Figure 4).



**Figure 4.** Graphic representation of research strategy

## 5. Findings and analysis

This section provides an analysis and discussion on the environmental, economic, and societal impacts of using natural stone for urban paving in Hanoi at all stages of the pavement life cycle. However, it should be stated at the beginning that the impact levels are various in different stages, which is also pointed out by researchers and scholars in the fields of transportation, pavement sustainability, and other related fields. The impacts are specific to the geographical and developmental context, which might result in the fact that some impacts found in cities elsewhere might not be found or be less noticeable in Hanoi while others might be amplified.

### 5.1. Environmental impacts

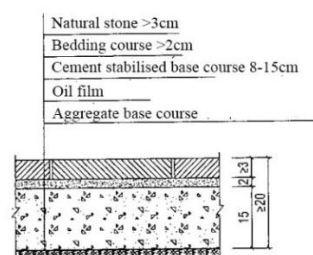
The concerns about the necessity of using natural stone and the application of it to all pavements in Hanoi have been raised. Out of many materials that are locally produced and have previously been used, including brick and compact concrete, and other environmentally friendly materials that are globally well-researched, experimented with, and produced, including pervious or permeable concrete, recycled materials, composite materials, and hybrid materials [19-23], the question of why only natural stone is consistently endorsed by the government has not been answered. The hypothesis is that the government has not been informed about the impacts of natural stone on the environment. This is based on the fact that there is still no scientific grounding to justify the selection. Hence, it is incumbent upon this paper to examine the actual environmental impacts of natural stone at all life cycle phases if they are recklessly applicable on a large scale.

*5.1.1. The impacts of the production of natural stone slabs.* Producing natural stone slabs has a damaging impact on the environment. This is due to the universal challenges of quarrying and processing these slabs. Research found that to deal with the harness and abrasiveness and to preserve the quality of the slabs, an extensive amount of electricity, water, diesel, energy, and labour is consumed during these two production stages, which contributes directly to releasing more greenhouse gas emissions [24, 25]. This environmental burden is determined by the utilisation of heavy machinery, cranes, trucks, auxiliary materials, a stainless or diamond wire saw, and many other tools to remove granite benches from the geologic deposit, transfer the stone benches or blocks to the temporary storage facilities, and ship or transport them to the processing facilities in the quarrying stage. In the processing phase, the burden is seen through the fact that stone blocks were cut into panels and then shaped into stone slabs with different sizes, shapes, and aesthetics to meet diverse demands from the market. Hanieh, AbdElall [26] found that the mining and manufacturing of natural stone cause serious problems for the environment,

including waste stone, dust production, powder, vibrations and noise, liquid sludge, and fuel emissions. To solve these problems, advanced technologies and equipment are needed but are often economically burdensome.

Regarding the granite stone slabs used for Hanoi pavements, most of them are transported from Thanh Hoa province (about 300 kilometers to the south), where they are being produced from scattered deposits. Although it is still unclear about the origin of these slabs, as it is almost impossible to gather data on this matter [27, 28]. According to the local press, hundreds of these deposits have been extracted from a number of quarries and mines built in the western part of Thanh Hoa province, where lie protective forests for the residents in the lower lands. In some places, such as Ha Tan ward, there are more than 10 quarries [29]. These quarries and the operation of these production plants have led to severe environmental damages, including deforestation, the loss of natural protective layers for the lowland residents, the disappearance of natural landscapes, air pollution, waste production, infrastructure degradation by frequent transportation by heavy trucks, and noise disturbances by explosives to surrounding residents [30-33]. High demands for city pavements as well as for construction industries have pushed many companies to overexploit or plunder natural stone deposits, leading to the point of exhaustion and further consequences, including potential landslides and dangerous excavation sites that are unable to recover or rehabilitate [29, 34].

#### 5.1.2. During construction phase.



**Figure 5.** Cross section of typical stone pavement used in Hanoi.

The construction of stone pavement has a significant impact on the environment, especially in terms of air quality. Unlike the paving of brick or concrete blocks, the paving of stone slabs often involves a range of activities and equipment due to its technical and mechanical complexity, as well as a wide range of other supplement materials (see Figure 5). More materials and machines involved in the paving process mean more work and processes are needed. The site preparation, excavation, processing, transporting, movement, and hauling of materials, as well as the operations of various types of heavy machines, enormously contribute to environmental burdens, which include energy consumption, GHG emissions, and impacts on the surrounding areas regarding emissions, airborne particles, and noise generation [4]. Especially, all of these impacts make the already polluted air in Hanoi even worse. The city's air quality has deteriorated in recent years, and construction, energy consumption, and a high volume of vehicles are found to be the main causes [35]. While much research investigating the exact contribution of the pavement construction sector to Hanoi's worsening air pollution should be carried out, it is arguable that simple materials with fewer related construction processes and activities should be endorsed in the Hanoi pavement rehabilitation case, not the one that piles up more environmentally negative effects.

5.1.3. *During the pavement use phase.* In the use phase, there are a number of negative impacts that stone pavements have on Hanoi's environment. Of significance are the increase in urban surface temperature and the increasing frequency of urban flooding during the hot summer and rainy season. Two of which are often the consequences of natural stone's physical and mechanical uniqueness.



Although research found that stone in general is a better material compared to asphalt or concrete in terms of reducing surface temperature owing to its high albedo effect or high ability to reflect solar radiation [1, 36]. This high albedo is associated with the lightness in colour and smoothness in texture of processed stone slabs, making it a cool pavement material that can reduce urban heat [5, 37]. However, it seems to be counterproductive to employ these perceived beneficial features into the weather and air quality of the tropical monsoon climate of Hanoi.

According to Benrazavi's [36] experiment, granite stone contributes to lower urban surface temperatures than asphalt and concrete due to its ability to absorb less solar heat (as also supported by other studies such as [38, 39]). However, the advantage is seen only in open spaces and under shaded areas. In near-water areas, the result was the opposite. The surface temperature increases if granite stone is installed in the vicinity of water bodies. The reason is that processed or polished granite stone has lower porosity and water repellent characteristics, which result in less heat exchange that leads to a higher surface temperature. Additionally, the lower surface temperature that granite stone provides was only proven in an open space with lower humidity and a large green coverage [36]. In the light of this research, it is arguable that Hanoi's climate, with its extreme high level of humidity (70% average), a significant number of annual raining days (120 days), high temperature, high urban density, and severely limited green coverage, does not seem suitable for the construction of stone pavements, especially at a large scale.

Another consequence of using granite stone for the pavement in Hanoi is urban flooding. At the present, there has not been firm evidence of the association between stone pavements and flooding occurrence in Hanoi. It is reported that Hanoi has had more and more flooding occurrences over years of urbanisation and the flooding situation has gotten worse [40-44]. While investigation into this matter is urgent, it is observable that stone pavement can be a contributing factor to this issue. The city's rapid urbanisation since the announcement of Hanoi Master Plan in 2008 causes the significant reduction in open spaces including green and blue areas (a rapid decrease from 2100 ha in 2010 to 1165 ha in 2015 [45]). These spaces play a critical role in water retention and act as a natural drainage system for the city. However, almost every piece of land has been used for buildings, infrastructure, and facilities to accommodate a large population. This results in the fact that the water absorptivity of the urban land has been significantly reduced as the urban surface has been extensively covered with building materials. At the same time, the drainage and sewage systems in Hanoi have lagged behind in coping with such rapid urbanisation [45]. The use of stone slabs with almost no porosity capability causes storm water to run directly into the underdeveloped drainage system, causing urban flooding on a large scale.

*5.1.4. During the maintenance phase.* The maintenance of pavement refers to all the actions and activities that can reduce the rate of pavement deterioration and waste production. The cracks and broken occurrences frequently found in Hanoi stone pavements pose a considerable burden to the urban environment. These concerns include the reconstruction of stone slabs, which involves a whole range of activities and processes causing GHG emissions, energy consumption, air quality reduction, and noise production, as mentioned in the previous section. The second concern is waste production and recycling. Unlike brick or concrete blocks, it is challenging and costly to recycle broken stone slabs due to their inherent hardness and abrasiveness. Therefore, most of them are considered construction waste and end up in landfills [46], causing a significant burden on the environment. It is also an enormous waste of non-renewable natural stone, whose quarrying and processing have already imposed significantly negative environmental impacts. The cycle is vicious.

## 5.2. Societal impacts

Since 2013, the public's reaction and criticism of the government's plan to change the appearance of the pavement has piled up. The majority of the Hanoians have been concerned about the conspicuous impacts after the construction of stone pavements was completed or after the stone slabs showed cracks. The overarching question frequently appearing in the press is how it is possible for natural stone that

has been labelled to have a 70-year lifespan to be broken after only two years. Many scapegoats have been made for the causes of cracks and broken stone slabs, including the blame for weather, for the heavy rains, for workers, for investors, and the like [47]. Too often, distrust and ridicule are directed at the authorities who created such scapegoats [14, 16, 48].

*5.2.1. During the production of natural stone slabs.* During the quarrying and processing of stone slabs, a number of social concerns have been raised. Firstly, there is concern about the safety and mental health of the local people living in the vicinity of stone quarries or plantations. The use of a large amount of explosive material to mine stone benches shakes the local residents' houses nearby and the ground, leading to landslides and enormous blasts in which pieces of broken stone blew into these houses, damaging them and threatening the residents' lives. Not only are the local people frightened by such incidents, but they are also affected psychologically [49, 50]. They are constantly worried about their lives, which are in great danger even in their own house and village. Another issue is the polluting sediment and dust produced from stone quarries and facilities. It has been reported that these pollutants were discharged directly to the irrigation system and farming ponds, causing water and air pollution that could potentially lead to respiratory health problems not only for the local people but also for the workers on the field [29].

*5.2.2. During the construction of stone pavements.* The impacts of paving the street sidewalks on the daily lives of Hanoians are most conspicuous. Many people whose house or apartment is close to the stone pavement streets reported that their lives and their businesses were disturbed by the lengthy and frequent process of installing stone slabs. Unlike other paving materials, it takes a longer time to install natural stone slabs properly due to a technically complex requirement, including the preparation of the subgrade, the aggregate and cement base courses, the bedding course, and the cutting and laying of the stone slabs. All of which requires a lengthy waiting period during which all residents, business operators, and visitors are temporarily prevented from or restricted from accessing the residential, commercial, or other functional buildings. This makes the construction areas less desirable, causing business failures and leading to delays in travel or traffic congestion. Most Hanoi streets are narrow and busy, and the pavements on both sides are often used for vehicles, especially during the peak hours. The traffic congestion and jams are bound to happen, not only on the construction site but also on the connected roads and streets.

Noise generated from the on-site processing and installation of stone pavements has a negative effect on the health of the residents nearby. The operation of heavy, powerful machinery, the haulage, and the cutting and handling of abrasive natural stone slabs result in excessive and intrusive noise, which is absolutely irritating and hazardous to the workers and surrounding residents. Research found that continuously hearing high noise can lead to hearing loss, sleep disturbance, communication interference or disruption, negative emotions, and stress-related health issues [51, 52]. Although no research has been conducted in Hanoi, the negative responses and experiences of the residents near the pavement construction sites are worth paying attention to [53, 54]. Future investigations into this matter are urgently needed.

*5.2.3. During the use phase.* The polished surface of stone slabs created to satisfy aesthetic demands causes the users many troubles. Users frequently report slips, trips, and falls while walking or driving on wet stone sidewalks. During hot summer days, it is uncomfortable and unbearable to use the pavement because of the high temperature and traffic fumes, accompanied by the solar radiation reflected back from the surface of the stone pavement and the nearby buildings. Stone pavements with a high albedo level are thought to reduce surface temperature, thereby mitigating the effects of urban heat islands (UHI). However, in the compact context of Hanoi city, users' experience and thermal comfort, especially when it comes to heat tolerance, must be seriously considered in every decision regarding paving and construction materials (as also suggested by [55]).



**Figure 6.** Issues with cracked and broken stone: (a) Always wet and slippery, (b) Water traps.

The severe cracks and broken pieces of the stone pavement often irritate pedestrians in various ways. A stone pavement with small areas of torn and cracked slabs scattered here and there is not aesthetically appealing, which runs counter to what has been initially perceived in the scheme. When it rains, these areas become temporal water containers or “water traps” (see Figure 6a, b). Every time someone unintentionally steps on them, there will be splashes of dirty water. The experience is, of course, unpleasant in such a case. By the same token, the stone pavements’ low porosity, in combination with the humid climatic conditions in Hanoi, results in a consistently wet surface due to their inability to be dried up, making the pavements look always messy and dirty. Broken pieces of the stone slabs are also waiting for pedestrians to hit them and fall over them, especially the elderly, children, or people with a visual impairment or disability.

### 5.3. Economic impacts

The use of a sustainable material will increase the cost-effectiveness throughout the life cycle of the pavement. From the production to the maintenance phases, using natural stone to pave the sidewalks seems not to be cost-effective. This ineffectiveness is possibly associated with the high price of a stone slab resulting from a high production cost and a high expenditure on fuels, labours, machinery, and frequent damages compared to other conventional materials. One of the major economic themes emerging from the online newspapers on natural stone utilisation in Hanoi is waste and ineffectiveness [56, 57]. The hypothesis has been speculated that by choosing natural stone for the pavement, the Hanoi government possibly tries to disburse its annual government budget. This association often emerged after the appearance of cracks and broken slabs. However, the economic costs of using natural stone to pave the city sidewalks can be examined during the beginning phase of slab quarrying and processing.

*5.3.1. The costs of natural stone extraction, production, and pavement construction.* Literature shows that there are many types of costs and expenses incurred during the extraction and production of stone slabs. Raw material costs, energy source costs, and operation costs are of significance [58]. The use of equipment, assisting materials, heavy machines, trucks, cranes, workers, electricity, water, and fuels when extracting, moving, shifting, transporting, and cutting the stone benches all come with a huge amount of capital. In addition to these costs, there are financial compensations for the land, the economies, the damages to property and infrastructure, and the health issues caused by the extraction and production for local people but often ignored [29, 59]. These costs are often not publicly known but are converted into the final price of a stone slab. The paper calls for investigation into this matter in future research to provide solid evidence on the actual economic costs of natural stone production.

According to the guidelines in Hanoi government Decision 4340/Q-UBND on pavement design and construction, there are two types of stone pavement structures: KC D1 and KC D2. The sizes of the stone slabs for these two types are 10cm to 40cm wide, 20cm to 60 cm long, and at least 3cm thick. The bid price with all costs added per square meter mentioned in the decision for any building contractor should not exceed 625.000 VND for KC D1 and 740.000 VND for KC D2. The typical price for one

square meter of stone slabs used for Hanoi pavements in the market ranges from 300 to 600 thousand VND (about 15 to 30 USD) with only transportation costs included [60, 61]. Even without mentioning the price variation from stone provider to stone provider and from district to district, these prices are much higher than those of other paving materials per one square meter unit. If applied to the street scale and then the city scale, the total cost is massive. An estimate of more than a thousand billion VND will be the total expenditure on stone pavements on more than 900 streets to meet the target set in the pavement rehabilitation scheme.

*5.3.2. The cost incurred during the use phase.* The economic costs of stone pavements often go unnoticed during the use phase, especially in the context of Hanoi, where there is no regulation on compensation or financial support for incidents caused by the pavement. Santos, Flintsch [58] mentions several economic costs incurred during the use phase, including fuel consumption, tire wear, and vehicle maintenance and repair. All of which rely on the roughness and macrotexture of the pavement surface. If the macrotexture of a pavement is characterised by low surface friction, particularly in a wet climate, the contact between the moving tire and the pavement surface will be reduced or lost. This leads to increases in vehicle speed, thereby boosting energy usage. More energy usage negatively affects the fuel economy. This issue is highly relevant in the Hanoi context as vehicles are often operated and parked on the pavement, but the fuel costs seem not to be paid attention to. Also, many traffic accidents, including vehicle falls and strips caused by wet and smooth stone slabs, have not been considered the responsibility of stone pavements but rather the fault of the users themselves for being careless. No financial support is provided for such accidents, which often involve user injuries, including pedestrians, the elderly, and people with disabilities, as well as damages to vehicles or goods in some cases [57, 62-64].

*5.3.3. During the maintenance phase.* The economic costs incurred by the frequent maintenance of cracked and broken stone pavements are considerable if all impacts are taken into account. These costs, on the one hand, include the business hardship suffered by shop owners and retailers during the maintenance period, time delay costs, and traffic congestion-related costs [4, 58]. On the other hand, the regular maintenance work for stone pavement is in itself an economic burden, as replacing cracked and broken slabs incurs material costs and expenses on fuel, energy, labour and the like. The fact that natural stone is loosely considered to last 70 years in the Hanoi government's plans but is damaged after 2 years of use shortens the maintenance service intervals and increases the amount of maintenance work over the life cycle of the pavement, which is really not cost-effective. This is possibly why concerns have been expressed about whether there is an act of disbursement in the government scheme to change the city pavement facelift [43, 48, 56]. The answer to such a question seems not to be forthcoming any sooner, as does the one questioning the economic costs of thrown-away cracked and broken stone slabs.

## 6. Conclusions

Using pavement sustainability as an analysis framework, this paper sheds a critical light on the environmental, economic, and societal impacts that result from the use of natural stone to pave the sidewalks by Hanoi's government. It reveals that natural stone pavements have a significant impact on Hanoi's environment, economy, and society at all life cycle stages, including material production, pavement construction, use, and maintenance. Natural stone production, including quarrying and processing stone benches and slabs, not only harms the environment but also jeopardizes its ability to recover. The overall environmental costs include deforestation, natural landscape disappearance, erosion, urban temperature increases, urban flooding, waste production, air pollution, noise pollution, and water pollution. Economically, using natural stone to pave the sidewalks is not cost-effective and is considered a waste of the national budget and natural resources. The processes of quarrying, transporting, and finishing stone slabs, as well as constructing and maintaining them, are costly and time-consuming, requiring more fuel, secondary materials, labour, heavy machinery, and other

equipment. This has a knock-on effect on other related industries that produce and cost the same products.

In terms of societal costs, natural stone production has a negative impact on the safety and mental health of local residents near production quarries and mines, whereas stone pavement construction causes prolonged disturbances, business disruptions, safety and health-related issues, traffic congestion, and sidewalk incidents to city residents, pedestrians, people with disabilities, and road users. Deeper and more precarious impact on the society implied from the analysis is the matter of trust in Hanoi's government's competency in making decisions, handling the consequences, and responding to the public reaction. It is arguable that Hanoi authorities prioritise aesthetic value to endorse the image of collectivism, endurance, and historic patriotism of a capital city over functional, environmental, and economical value. The results are counterproductive. Stone-paved streets are not aesthetically pleasing, especially during rainy seasons. They are not durable enough to last 70 years as expected and are used for parking cars and other vehicles, not just pedestrians. Falls, strips, slips, and discomfort to walk on during hot seasons are not features that Hanoians want for any collective or public goods.

Finally, through the analysis, important themes have emerged that need further investigation. First and foremost is the urgency of quantitative research that employs a life cycle assessment to provide comprehensive and solid evidence on the impact level of the stone pavements on environment, economy, and society that have been discussed earlier. The environmental impacts in connection with tropical climate and climate change should be given more attention. Research needs to focus on issues regarding urban heat islands, thermal comfort for users, noise generation, and urban flooding resulting from stone paving. More tools and methods need to be established to measure the true economic costs in the production phase and over the life cycle of a stone pavement. Presently, figures of such costs are not publicly available, which causes rumours and conspiracy theories that can become more dangerous if not approached appropriately.

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