LOCAL SEISMIC CONSTRUCTION PRACTICES AS A MEANS TO VULNERABILITY REDUCTION AND SUSTAINABLE DEVELOPMENT

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ABSTRACT

By conceptualising local seismic construction practices as capital, this paper proposes a theoretical framework within which its conservation can be envisioned as a means to reducing vulnerability and moving towards more sustainable development. The application of the proposed conceptual framework is demonstrated in the case of Lefkada Island in Greece. Each of the four key constructs (local seismic construction practices, physical vulnerability, social vulnerability, perceptions of local seismic construction practices) that constitute the framework are analytically examined, while inter-relationships between the key constructs are hypothesised and corroborated through the integrated interpretation of the findings emerging from the study of the individual constructs. In particular, measures of social vulnerability are developed which are used to discern different levels of social vulnerability on the island. The influence of social vulnerability on perceptions of the local population pertaining to conservation of local seismic construction practices is subsequently demonstrated. The physical vulnerability relating to the building stock is assessed through damage data of the August 14, 2003 earthquake, and vulnerability curves are developed for the building typologies found in Lefkada. A hypothetical loss scenario is examined that demonstrates, through comparative means, the importance of local seismic construction practices in reducing physical vulnerability, and subsequently expected losses. The research also studies the contribution of conserving local seismic construction practices, to reducing vulnerability and moving towards more sustainable development.

KEYWORDS

Vulnerability, sustainable development, local knowledge, principal component analysis, cluster analysis

1. INTRODUCTION

The study and conservation of local seismic construction practices, as a valuable source for technical learning, has been recently recognised [1-4]. However, a conceptual gap is identified in addressing their conservation in the wider context of vulnerability reduction and sustainable development, compromising the potential for success of supportive policies [5]. The overarching objective of this study is to demonstrate the significance of conceptualising local seismic construction practices as a means to reducing vulnerability and moving towards more sustainable development. In particular, the sub-objectives are i) to provide a theoretical framework within which local seismic construction practices can be conceptualised as part of vulnerability reduction and sustainable development and ii) to demonstrate the application of this framework in the chosen case study, developing appropriate methods, where necessary.

2. CONCEPTUAL FRAMEWORK

Using sustainable development as a conceptual tool, local seismic construction practices need to be considered within the broader contexts of *sustainability* and *development* and thus their conservation needs to be examined beyond the confines of an earthquake engineering perspective. The feasibility of their conservation will almost certainly depend equally, if not to a greater extent, on wider economical, social and environmental considerations [6].

A starting premise of this research is that *sustainability* is based on the notion of conserving capital [7], which points to the conceptualisation of local seismic construction practices as capital in themselves [8]. While several forms of capital have been identified (e.g., natural, social, human, manufactured and financial capital), distinctions among them are not always simple. Classification, however, is not critically important, as most capitals are interdependent and co-exist both in meaning and practice. The importance stems from the very conceptualisation of local seismic construction practices as a form of capital, as this offers a basis upon which different perspectives are argued and may be evaluated. Borrowing from *ecological economics* in order to elaborate on this point, the theoretical proposition of *capital substitutability* [9-11] is considered *vis-à-vis* the notion of *development*.

In its earlier conception, *development* was understood from a purely economic perspective and was frequently employed synonymously to *growth*, realised through the expansion and increase of manufactured and financial capital to the detriment, most frequently, of natural capital [12, 13]. However, later on, the advocates of *ecological economics* came to understand *development* as distinct from *growth*, adopting the former to describe *qualitative* rather than quantitative change. This distinction provides the first point of criticism of the technocratic approach, whereby *development* is perceived as the expansion of the physical quantity and technological capabilities of human capital [14]. A definition of development as growth renders the concept of *sustainable development* (growth) an oxymoron, as it implies an endless increase in quantity, neglecting limits to growth, which have been long established [15, 16]. This demonstrates that sole reliance on technological renewal and subsequent (economic) growth is not sustainable in the long term. However, a definition of development as qualitative improvement renders *sustainable development* a meaningful concept [17-19]. Qualitative improvements, in this research, may be perceived in the form of physical and social vulnerability reduction through conservation of local seismic construction practices (i.e., human/cultural/manufactured capital).

Commonly, development is called sustainable when it leaves the total capital stock at least unchanged, if not improved [20-23]. In other words, in addressing *inter-generational equity*, development is sustainable if the next generation has at least as much capital as the preceding generation. Within this dominant view, however, total capital conservation has been interpreted differently and debates have culminated into what is formally known as the *capital substitutability* theory with the establishment of two main opposing camps, the *weak* and the *strong* [24]. The fundamental element of dispute is based on the interpretation of capital *conservation* in regard to its *exclusion of* or *allowance for* change. Given that total capital comprises of five (or more) interdependent sub-capitals, questions are raised as to the extent that capital stocks are to be conserved in their *aggregate* form, thus, allowing for substitution between the various forms of sub-capital or whether each sub-capital should be conserved *per se* (leading, naturally, to overall capital conservation), without allowing for change to occur in the form of substitution. For advocates of *weak sustainability*, substitutability is permissible such that one form of capital may be reduced, as long as another form is augmented accordingly [25]. Technocrats embrace a weak sustainability stance, as they tacitly accept the depletion of natural and cultural capital by conversion to manufactured and financial capital [26]. Under this perspective, it may be argued that, local seismic construction practices should be substituted by state-of-the-art technology and the more advanced knowledge pertaining to such technology. This approach is fostered by much of the current training and practice of engineers, whereby university curricula, research programmes and design codes exclude, in most cases, the study, experimentation and use of local materials and practices [27, 28]. Advocates of *strong sustainability*, however, argue that for development to be sustainable, it is not sufficient to maintain a total aggregate capital, but instead to preserve individual sub-capitals *per se*, as at least parts of these sub-capitals (termed, critical portions) are non-substitutable (i.e., they complement each other) [29, 25]. In particular, it is the natural capital that needs to remain constant over time, given that some of its stock is non-renewable. According to Turner [30], this view is founded on the principles of *uncertainty* over the functioning and total value of sub-capitals, *irreversibility* stemming from degradation and loss of sub-capitals, *criticality* of some sub-capitals (especially natural capital) and the relative scale between one sub-capital in respect to another.

Under such a perspective, local seismic construction practices and the buildings constructed with such practices may be perceived as a non-renewable form of capital and therefore should be conserved intact, as a legacy to future generations. Critics may, however, argue the absurdity of this extreme form of strong sustainability on the grounds of countering the continuous and unavoidable process of evolution, stifling, thus, development [30, 31].

Furthermore, such an extreme perspective fails to address the shortcomings and incompleteness of any form of knowledge or artefact, by resisting change and innovation and assuming that non-renewable resources should never be used up [32].

It becomes clear that a spectrum of sustainability conceptions has emerged over the years, with *weak* and *strong* occupying the very ends of the spectrum and moderate (weak or strong) sustainability the space in between. In regard to this research, a (moderate strong) sustainability approach would entail the conceptualisation of local seismic construction practices as capital, whose conservation needs to be addressed not only vis-à-vis its perceived physical purpose (i.e., with regards to the physical vulnerability of buildings constructed with such practices), but also vis-à-vis the effects its conservation will have in the wider context of development (i.e., to what extent this conservation is feasible and desirable), as advocated also in the Charter on the Built Vernacular Heritage [33].

Until recently, for engineers (and other technically based specialists), local seismic construction practices have rarely comprised an explicit subject of inquiry. In most cases, it was the buildings constructed with such practices that have posed concerns over their conservation. However, for engineers, conservation is likely to be premised upon the structural ability of buildings to resist future earthquakes and provide adequate levels of safety; namely, avoiding collapse and minimising damages [34]. While unarguably structural capacity is a critical concern in the decision-making process over the buildings' conservation, assessment of physical vulnerability and establishment of required actions for structural strengthening, repair and maintenance are unlikely to resort to conservation of local seismic construction practices *per se.* In other words, for local seismic practices to be conserved, they need to be actively applied in the construction of new buildings and not only in the *ad hoc* repair of existing structures following earthquake damage. This is a second point of criticism of the technocratic approach, which by failing to conceptualise local seismic construction practices as capital, limits decision-making on technical grounds and allows the gradual degeneration of a, strictly speaking, non-renewable resource [35].

The conceptualisation of local seismic construction practices and the buildings constructed with such practices as capital extends the debate over its conservation to a much wider group of stakeholders. In this view, conservation is no longer confined to the judgment of experts [8], albeit this is of crucial importance, but involves also those directly affected by the outcomes of the decision-making process [36]. Consequently, this leads to a more participatory process addressing, to some extent, *intra-generational equity* [8] and providing useful insights [37] on the major obstacles that are perceived to render the conservation of local seismic construction practices unfeasible. In addition, the perspectives of many stakeholders are likely to inform better future development plans and policies and ensure their long-term effectiveness, as it is now widely recognised that failure to account for the needs, aspirations and attitudes of local people jeopardises the success and survival of future policies [38].

Borrowing from *cultural ecology*, an important hypothesis formulated by Firey [39] states that the interaction of socio-economic, ecological and cultural aspects plays an important role in determining local perceptions over resource management (in other words capital conservation). Empirical evidence in support of this hypothesis [38] suggests the importance of interpreting local perceptions with regards to the demographic, socio-economic and cultural backgrounds of their holders. Under the vulnerability discourse employed in this research [5], this is effectively understood as the influence of different levels of social vulnerability on people's perceptions. It follows, therefore, that it is necessary to establish how different forms and levels of social vulnerability condition perceptions that in turn affect the decision-making with regards to capital conservation by local stakeholders.

By synthesising the key ideas introduced in the previous discussion, the following conceptual framework (Figure 1) is proposed for this research, seeking to explore the contribution of conserving local seismic construction practices as a means to reducing vulnerability and moving towards more sustainable development. While some authors have recently demonstrated the benefits of conserving local construction practices with regards to augmenting social, financial, environmental and manufactured capital [7, 40] and, thus, their contribution towards sustainable development, such practices have not been, explicitly, linked to the context of vulnerability.

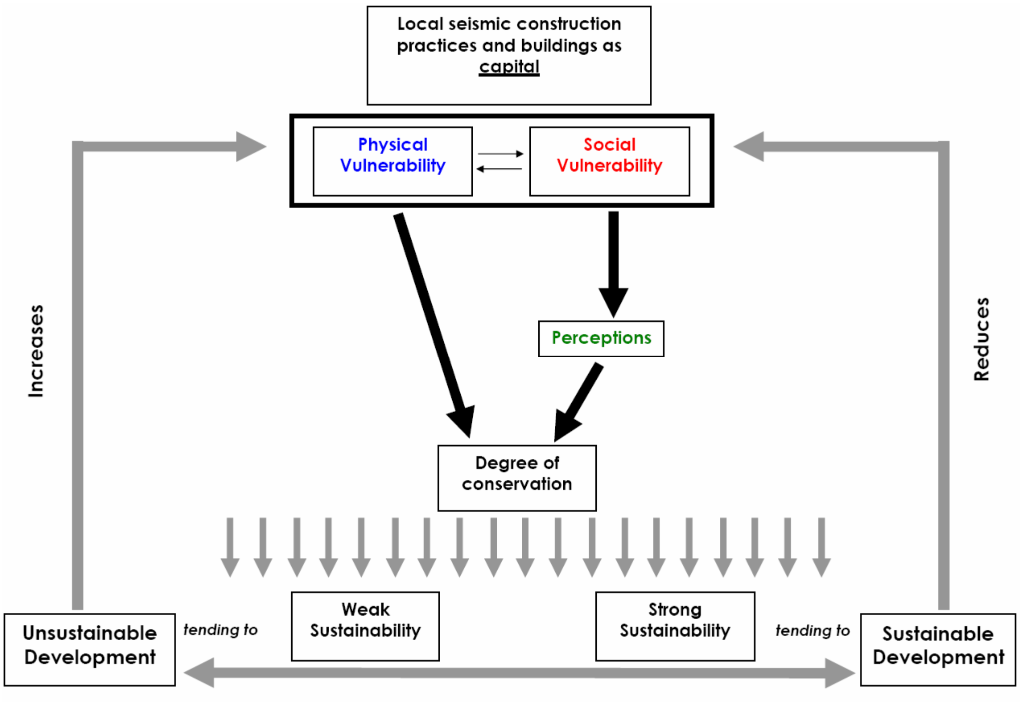

Figure 1: Proposed conceptual framework

FRAMEWORK APPLICATION

3.1 Local seismic construction practices (LSCP)

Lefkada Island off the west coast of Greece was chosen as a suitable case-study for the application of the framework as the research intentionally focuses in a high HDI[1] country and an area of high seismicity, whereby LSCP have developed and are still used to a limited extent today.

Local seismic construction practices in Lefkada comprise a dual system of stone masonry (LBSM) and timber frame (TF) structures. A typical building consists of two storeys (4-5 m in height) with stone masonry found on the ground storey and timber frame on the first storey. The first storey is supported by the stone masonry of the ground storey, as well as an additional set of timber columns erected in the interior of the ground storey. This secondary (or in some cases primary) system of support, known in the local vernacular as *pontelarisma,* is what makes this construction system unique.

These practices demonstrate typically several principles of good seismic performance such as: sufficient ductility through the provision of appropriate connections, adequate stiffness through the use of stone masonry and timber elbows, structural redundancy that ensures safe failure, structural independency between the two systems to avoid pounding, strength reserves due to over-design of timber members, multiple paths of load transfer, enhanced damping through infill compartmentalisation, diaphragmatic action of roofs and floors, lateral bracing to resist shear forces, moderate height of storeys, moderate weight of storeys to be carried by the ground storey, symmetrical openings in plan and section as well as regular layouts [41].

However, knowledge degeneration coupled with changing needs and socio-economic contexts have imposed changes in the use and function of structures. For example, the conversion of the ground storeys of many buildings into shops has led to the demolition of the stone masonry walls and their replacement with glass facades. This, in turn, has lead to a critical loss of stiffness of such structures, in cases where the masonry serves

[1] HDI: Human development index as proposed by UN (see: http://hdr.undp.org/reports/default.cfm)

as the main stiffening element [42], compromising, thus, the seismic safety of such structures. This implies the pronounced need to study such practices as part of the wider development context in which they currently exist.

3.2 Social and physical vulnerability

Social vulnerability was assessed using Principal Component Analysis (PCA) applied to a series of indicators (e.g., age, gender, education, income level, built environment, geographic location) for each of the forty districts of Lefkada. The application of PCA allowed for significant reduction in the number of dimensions across which districts need to be compared in order to identify common levels of social vulnerability among them. The original data compiled from the latest national population and building censuses [43, 44] was reduced to a more comprehensive set comprising four principal components; namely, lack of access; oldness of building stock, density and mobility. The principal components were then used to delimit groups of districts characterised by maximum within-group similarity and between-group dissimilarity; a process known in mathematical terms as cluster analysis [5]. The optimum number of clusters was identified as two; one representing the more rural interior and declining districts of the island, while the other the more urban coastal and expanding districts (Figure 2a).

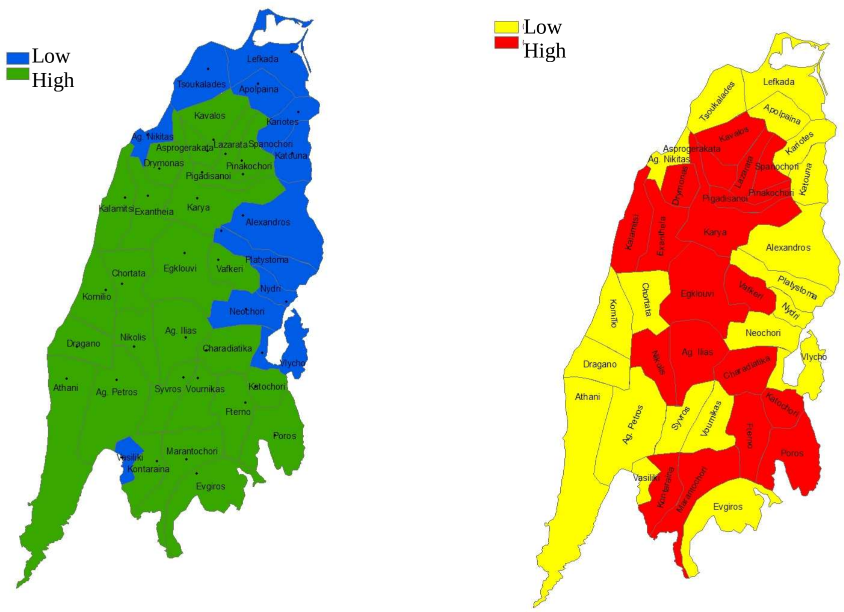

Figure 2: Social (a. left) and physical (b. right) vulnerability of districts

A physical vulnerability assessment was undertaken based on damage data collected after the August 14, 2003 earthquake and complemented by worldwide data [45]. The *PSI* methodology developed by Coburn *et al.* [46] was used to obtain a first estimate of the vulnerability of the building stock of Lefkada. Vulnerability curves were then developed for each of the main structural typologies identified on the island. Figure 3 shows indicatively vulnerability curves developed for load bearing stone masonry structures (LBSM) and buildings constructed with Lefkada's LSCP (LBSM & TF) (constructed between 1945 and 1960). LBSM & TF is shown to perform better than LBSM, demonstrating therefore its conceived role as an improvement to the latter class. This finding is important in view of the potential application of the secondary system of support (post construction) as a strengthening means to the existing LBSM building stock. In general, LBSM & TF buildings appear more vulnerable than reinforced concrete frame buildings [5].

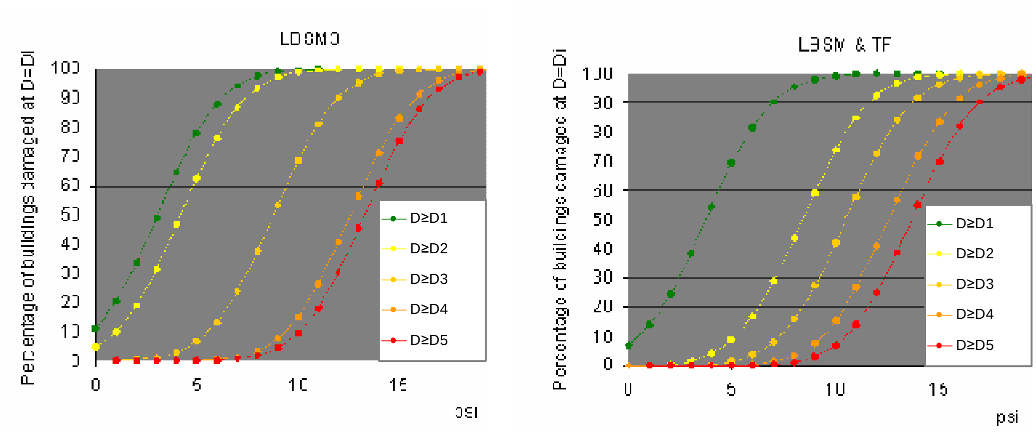

Figure 3: PSI-based vulnerability curves developed for building typologies in Lefkada

To estimate the vulnerability of the stock in each district of Lefkada, each damage grade was first assigned a central damage factor (CDF), which represents the ratio of the cost of repair over the cost of replacement of a building, expressed as a percentage. This allowed the computation of a loss ratio for each district, under a hypothetical earthquake scenario. Through comparison of the computed ratios, the relative vulnerability of the stock of each district was assessed. In order to compare the levels of physical and social vulnerability at the district level, clustering of the districts based on the obtained loss ratios was performed using the *TwoStep* method, and verified by Ward's and the k-means methods (Figure 2b). Similarities may be discerned among patterns of social and physical vulnerability. In fact, a highly significant, strong correlation was found between the two constructs (variables) (r=0.66 p=0.01), confirming the initial hypothesis. Finally, superposition of physical and social vulnerability patterns in Lefkada revealed that a more appropriate demarcation of its districts amounting to what might be called *composite* vulnerability, may be based on a three-cluster unit of analysis (Figure 4).

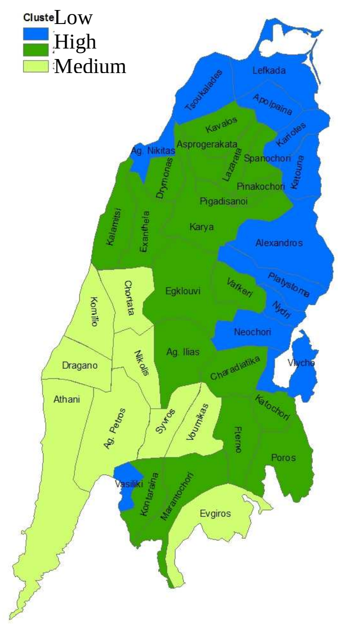

Figure 4: Composite vulnerability by superposition of social and physical vulnerability

For the districts of cluster 1, social and physical vulnerability were both shown to be lowest, in comparison with the remaining districts of the island. For the districts of cluster 2 the converse was shown to be true. Districts of cluster 3 were shown to have high levels of social vulnerability, but low levels of physical vulnerability. This finding has significant implications for local planners, as it demonstrates how partial approaches to vulnerability may fail to identify areas where *composite (total)* vulnerability is likely to be highest, and to highlight the need for prioritisation when drawing strategies towards vulnerability reduction.

3.3 Perceptions

Perceptions of local seismic construction practices were analysed by means of data collected by a questionnaire, with the aim of exploring differences in perceptions and behaviours between the populations of the two clusters and examining thus the hypothesised link in the proposed framework. Significant differences in perceptions held by the respondents in each cluster, as well as their behaviour vis-à-vis construction and attributes of their residences, were detected for more than half of the included questions. The key barriers for the conservation of the unique local seismic construction practices found in Lefkada (LBSM & TF and TF), as perceived by both groups of respondents, are considerations pertaining to purchase/construction costs, maintenance lifetime costs, and incompatibility with basic building requirements [5].

While earthquake safety and cost considerations are the most fundamental factors for all questionnaire participants, the respondents of cluster 1 appear to be more sensitive to environmental, aesthetic and landscape compatibility issues, while those of cluster 2 appear more concerned with the support of the local economy. With regards to trade-offs, earthquake safety is considered by all respondents as the parameter to be least compromised. However, while this may be perceived as the desired behaviour in decision-making (i.e., prioritising safety in earthquakes above all other parameters), the mismatch between those residing in timber-frame buildings and those considering timber-frame buildings to be the safest construction material and practice reveals that behaviours do not always adhere to perceptions. Respondents in cluster 2 tend to aspire to more contemporary construction practices and the associated (perceived) improvements in the quality of habitation, and are likely to prioritise this aspiration over other concerns. However, support of the local economy is among their key criteria, given their deprived economic conditions. Respondents in cluster 1 appear to be more willing to prioritise environmental, ecological and social concerns over cost concerns. These findings may be better understood and more formally explained by Inglehart's [47] theory postulating that '*people with* '*Postmaterialist' values – emphasizing self-expression and the quality of life – are much more apt to give high priority to protecting the environment* […], *than those with 'Materialist' values – emphasizing economic and physical security above all*'.

Taking into account the historical evolution of the two clusters, and the current demographics in each one, it can be seen that the older and less educated population, which Inglenhart terms *Materialist*, is found in cluster 2. This population is the most economically deprived (living under the poverty threshold) and occupies the oldest stock, constructed in its majority of stone masonry. Furthermore, physical security in earthquakes appears to be still a major concern for this population, as the levels of perceived safety reveal. It becomes clear from Inglerhart's theory, that for this part of the population, conservation of local seismic construction practices is only likely to be endorsed, if the direct links of the contribution of conserving this form of capital to the less developed and highly desired forms of capital (e.g., financial) are made explicit. For the population in cluster 1, however, conservation may be endorsed not only on the basis of economic benefits, but on perceived social, aesthetic and environmental benefits for the island. This is an important finding for decision-makers at the local authority level, which should be taken into account when drafting policies to incentivise the local population towards conservation of LSCP and buildings constructed with such practices. The analysis highlights how local context can be taken into account and how local knowledge of the population vis-à-vis its needs and aspirations is likely to offer valuable information towards effective policy-making.

5. MAIN CONCLUSIONS

The application of the proposed conceptual framework to the chosen area of study revealed among others i) a high degree of correlation between patterns of social and physical vulnerability; ii) the significance for planners to consider *composite* vulnerability rather than partial conceptions (physical or social), in order to demarcate appropriately and attend to the needs of, the most vulnerable areas; iii) the influence of social vulnerability on perceptions pertaining to capital conservation, and consequently the importance for planners and decision-makers to address the different needs and priorities of the concerned populations when drafting relevant policies [5]. Indicatively, it is acknowledged that further work is necessary in order to refine the proposed framework and examine its applicability in different settings.

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