"NON-ENGINEERED 2.0" – RENEWED PHILOSOPHIES FOR IMPROVING THE SEISMIC PERFORMANCE OF NON-ENGINEERED CONSTRUCTION

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Abstract

Design Philosophies, Technological Strategies, Non-Engineered Construction, Local Material Properties, SMARTnet

This critical writing questions the current state-of-the-art and knowledge levels with regards to non-engineered construction techniques in general, and rubble stone masonry in particular. In-depth reviews show that the available information in the national codes, technical regulations and practical manuals is largely outdated, contains many contradictions, and has become ambiguous. This raises questions about the completeness and correctness, as well as about the reliability and actual value of the knowledge in this field.

The term "non-engineered" in construction refers to building as "those which are spontaneously and informally constructed in various countries in the traditional manner, without any or little intervention by qualified architects and engineers in their design". Such techniques generally do not behave well in earthquakes, and the most devastating levels of damage and loss generally occur in developing countries, such as the recent disasters in Kashmir (2005), Haiti (2010) and Nepal (2015). Fact is that millions of people will continue to live in stone houses in India, Nepal, Pakistan, Bhutan, Afghanistan, China, and likely in regions in Central Asia, the Middle East and Northern Africa as well.

So how can we accurately predict and significantly strengthen the seismic performance of these techniques, yet with basic engineering principles? How can we improve the quality of local construction practices with simple skills, and effectively implement national standards in affordable ways? These key questions have not been adequately addressed to date. Vernacular building types include numerous variables that are highly dependent on site-specific parameters for local construction quality, materials and workmanship. From an engineering perspective, these variables are not integrated in current calculations and models, and a methodology that includes such parameters is currently non-existent.

The authors of this paper clearly acknowledge the need for renewed insights and a drastic change of attitude, which requires full-time dedication and a structured, systematic and scientifically based long-term approach, in order to significantly improve the seismic behavior of non-engineered techniques. To achieve this, renewed philosophies and technological strategies are necessary, as the time has come for "Non-Engineered 2.0". Several recommendations and solutions are proposed under the name SMARTnet, which stands for "**S**eismic **M**ethodologies for **A**pplied **R**esearch and **T**esting of **n**on-**e**ngineered **t**echniques".

It is realized that the challenge is huge and the scope of work enormous, for which help is needed. The strategy of SMARTnet envisions a joint approach of global collaboration, in order to cope with the massive number of material variables and to generate cross-checked data that can be used for calculations and computer modeling of non-engineered techniques. SMARTnet therefore places an international call for collaboration and invites experts, professionals, academics as well as final-year students in these fields to exchange their knowledge and to support the project with their time and expertise.

1. Introduction

Between 2007 and 2012 the Dutch non-for-profit organization Smart Shelter Foundation (SSF) built several earthquake resistant schools in rubble stone masonry and cement block masonry in Nepal. The designs were made by Martijn Schildkamp, architect and first author of this paper, and the design rules were obtained from the numerous technical guidelines and practical manuals that can be found online. These general rules of thumb are commonly referred to as "best practice" or "non-engineered construction principles". Prof. A.S. Arya, one of the pioneers of research on the seismic behavior of such techniques, defines non-engineered buildings as "those which are spontaneously and informally constructed in various countries in the traditional manner, without any or little intervention by qualified architects and engineers in their design" [1].

While preparing designs with the available knowledge, it was the personal experience of Schildkamp that the information was often unclear, contradictive and incomplete. During the construction of the projects many technical questions and practical issues came to light which were not properly addressed in the literature. Although all 15 schools as built by SSF with reinforced bands have withstood the 2015 Gorkha earthquakes without any significant damage, generally rubble stone masonry structures do not behave well during a seismic event. As was painfully shown during the recent disasters in Kashmir (2005) and Nepal (2015), both resulting in high casualties. Around 980.000 schools and houses were damaged and destroyed throughout Nepal, of which 80% took place in the rural areas, where 95% of all collapsed structures consisted of low-strength rubble stone masonry, of which the majority built with mud mortar [2]. Main reasons for the large-scale destruction are the lack of seismic-resilient features, and deficiencies in design, detailing, material and craftsmanship.

However, stone masonry using local skills and resources remains to be the predominant local structure in many developing countries in earthquake zones. Especially in the Himalayas, but also in many countries in Central Asia, the Middle East, Northern Africa and Eastern Europe the technique is still being practiced today. Table 1 shows that most damage and devastation due to earthquakes usually takes place in developing countries, both in terms of casualties, as well as in terms of relative financial loss [3]. Therefore, a primary question we need to ask ourselves is: Have we done enough to reduce and minimalize the losses in these regions? If the answer is negative, then the obvious next question is: How can we improve this situation? The following chapter examines and questions the current state-of-the-art of the overall knowledge with regards to the design and construction rules and regulations of non-engineered techniques in general, and with focus on the technique of rubble stone masonry in particular.

Table 1 – Casualties and economic loss figures of historic earthquakes since 1900

	Loss of Life (highest estimated)			
1	1976	Tangshan	China	655,000
2	1920	Haiyuan	China	273,400
3	**2004**	**Indian Ocean**	**Indonesia**	**227,898**
4	**2010**	**Haiti**	**Haiti**	**160,000**
5	1923	Great Kanto	Japan	142,807
6	1908	Messina	Italy	123,000
7	1948	Ashgabat	Turkmenistan	110,000
8	**2005**	**Kashmir**	**Pakistan**	**100,000**
9	**2008**	**Sichuan**	**China**	**87,586**
10	1970	Ancash	Peru	70,000
11	1935	Quetta	Pakistan	60,000
12	1990	Manjil-Rudbar	Iran	50,000
13	**2001**	**Bhuj**	**India**	**20,023**
Top 5 most recent in **bold;** 4 out of 5 in **developing** countries (total 10 out of 13 (currently) in **developing** countries)				

	Economic Loss as Relative % of GDP			
1	**1988**	**Spitak**	**Armenia**	**358.9**
2	1972	Managua	Nicaragua	105.0
3	1910	Cartago	Costa Rica	90.0
4	1906	San Francisco	USA	82.9
5	**2010**	**Haiti**	**Haiti**	**70.0**
6	**1993**	**Wallis/Futuna**	**Fiji**	**54.0**
7	1923	Great Kanto	Japan	52.8
8	1931	Nicaragua	Nicaragua	51.0
9	**1976**	**Guatemala**	**Guatemala**	**50.3**
10	**2015**	**Gorkha**	**Nepal**	**50.0**
Top 5 most recent in **bold**; all in **developing** countries (total 8 out of 10 in **developing** countries)				

2. Reviews of Available Literature

2.1 Terminology

The following structural system is reviewed in this paper: “Nominally reinforced random rubble stone masonry that is brought to courses and executed with cement mortar”, as shown in figure 1. This construction type can be sub-divided into the following elements:
- Type of building
- Type of stone masonry
- Type of stone unit
- Type of mortar
- Structural system
- Horizontal and vertical reinforcements
- Masonry patterns and detailing


Figure 1 – Random rubble stone masonry with cement mortar, brought to courses with proper bonding, and nominally reinforced with concrete bands (by courtesy of Smart Shelter Foundation).

As for building types, the possibilities and limitations are analyzed for single-family houses and small-scale school buildings, as currently still (or potentially could be) built at various places in the world. The type of stone masonry can essentially be brought back to two main categories: Rubble stone masonry and Ashlar masonry, which depends on the specifications of the stone units, such as shape and dimensions. Rubble stone units may refer to round boulders and stones of irregular shape that are uncut, unevenly split, unsquared and un-dimensioned. On the other hand, stones that are cut, squared and dimensioned into a regular sized parallelepiped shape, are called Ashlar. When stones are more evenly and consistently shaped like bricks, it will be easier to build straight and stable walls. But the process of shaping is time-consuming and costly, and therefore Ashlar is seldom used for rural and remote construction in developing countries.

The choice of mortar type has a huge impact on the strength characteristics of the masonry. This review is focusing on cement-sand mortar as it is suspected by the authors that stone masonry with mud mortar will not meet the strength requirements due to dynamic shaking. The widespread damage in Nepal seems to confirm these suspicions, but this hypothesis needs further validation.

As for detailing and reinforcements, based on expected seismic hazard there are certain rules to be followed with regards to the overall dimensions of the building and its individual elements, such as minimum or maximum heights, lengths, thicknesses and sizes of openings. Of further influence on the overall strength and stability of the masonry is the detailing of the walls, such as the laying and bonding patterns of the stones. Care must be taken at all critical sections such as corners and t-sections, around openings. Wall wythes must be connected with so-called through stones that run over the full thickness of the walls at certain intervals. Figure 2 shows different stone units with different mortar types and laying patterns, where it is expected that each consecutive example performs better during an earthquake.

Figure 2 – a) Round river boulders with mud mortar; b) Random rubble stone masonry with mud mortar; c) Random rubble stone masonry brought to courses with cement mortar; d) Ashlar stone masonry with lime-sand mortar (all by courtesy of Smart Shelter Foundation).

All the above-mentioned elements come together in the choice of structural system. Based on "characteristics relevant to its structural response under multi-hazard actions" [4], masonry is generally divided into 3 main types. These are Unreinforced Masonry (URM), Confined Masonry (CM) and Reinforced Masonry (RM). Reinforced Masonry consists of an embedded grid of horizontal and/or vertical reinforcements that act together with the masonry units in resisting lateral forces in both in-plane and out-of-plane directions. Confined Masonry walls act as shear panels due to a combined action with the reinforced concrete confining members such as horizontal tie-beams and vertical tie-columns, that are cast around the wall units. RM can be calculated and the codes usually require full validation; CM generally does not.

Unreinforced masonry however, as the name implies, has no reinforcements whatsoever, and since URM buildings have never behaved well during a seismic event, the technique is not allowed to be used in any seismic code worldwide. Still, quite a few countries describe URM in their codes but with the addition of certain horizontal and vertical reinforcements, making it Reinforced Unreinforced Masonry, or Unreinforced Masonry with Reinforcements at best. For instance, the Iranian seismic code [5] has included a separate chapter called "masonry buildings with ties", which mainly describes confined masonry, but which is classified as URM as this code makes a distinction between URM and RM only.

These days Confined Masonry is often described as "semi-reinforced masonry", a term that also applies to loadbearing walls with horizontal bands, although both systems structurally behave very different. To enhance clarity and to avoid further confusion, this writing calls for the introduction of a new and fourth category of masonry and proposes the international adoption of the term "Nominally Reinforced Masonry" (NRM) for walls that are nominally strengthened, next to the existing types of URM, CM and RM.

2.2 Rubble Stone Masonry in National Seismic and Masonry Codes

While submitting this writing for 17WCEE, a worldwide review of over 200 national seismic and masonry codes is currently on its way, with specific focus on rubble stone masonry buildings. All codes are translated from their original language and checked by representatives of each country. The results cannot be printed yet as the paper is under peer-review, but at this stage a number of interesting overall points can be raised. In the following paragraphs only the code names are mentioned (in brackets); Full references are included in the upcoming paper on this topic [6].

Historically, rubble stone masonry was used abundantly in many parts of the world, but due to its weak performance in past earthquakes most countries have either gradually reduced its application or have completely removed stone masonry from their codes. Currently rubble stone masonry is only allowed in India, Nepal, China, Tajikistan, Turkmenistan, Uzbekistan, Armenia, Georgia, Iran, Croatia and Italy. In Europe most countries have adopted Eurocode 8 (EN 1998-1+A1-2013) for seismic design, which refers to

Eurocode 6 (EN 1996-1-1-2005) for masonry, which refers to the requirements for “Natural Stone Masonry Units” (EN 771-6-2015). This code clearly describes that the stone masonry units must be dimensioned, thus only permitting Ashlar Masonry. Countries are allowed to introduce additional requirements in their national annexes, which only Croatia has done by adding rubble stone with certain minimum mechanical properties. The point to make here is that the European countries have clearly described the stone properties. In most Central Asian countries for instance, these are less clearly defined. The earlier Russian codes from the 1950’s allowed irregular stone, but since 1981 the Russian seismic code (SNiP II-7-81*) only mentioned certain types of sawn and dimensioned stones, without explicitly ruling out rubble stone. The Uzbek code (KMK 2.01.03-96) has copied these clauses, but it is generally assumed that “stones of regular shape” relates to rubble stones simply because this material is still abundantly used in Uzbekistan, whereas dimensioned stone is uncommon [7]. The seismic code of Tajikistan (MKS CT 22-07-2007) has included one extra word to the clause and “recommends” that stones must be of regular shape. Even though in several countries rubble stone is not explicitly ruled out, it would be extremely helpful if the codes add just one or two lines that simply state which types of stones or techniques are allowed, and which ones aren’t.

In all countries that are situated in the Himalayan region, stone is still a primary building material. However, Bhutan has no seismic or masonry code as of date. Pakistan, where it is estimated that 5% of the building stock is still constructed in stone [8], has not included this material in their codes. In Afghanistan less than 20 years ago it was estimated that 90% of the building stock consisted of non-engineered structures made of mudbrick and stone [9]. However, Afghanistan has recently published their first unified Afghan Building Code (ABC-2012) which is basically a collection of literally copied segments of US-based codes and references to ASCE and ASTM norms, which ultimately only addresses Ashlar masonry. Besides, not many engineers in Afghanistan will have access to all these separate documents. The Indian and Nepali codes, which both have no mandatory status, only allow housing designs and do not permit the construction of school buildings in stone masonry. Especially in Nepal this poses a problem, as stone is basically the main option to build with in the remote mountain areas.

All these examples have one important thing in common; they do not properly reflect the current needs in their respective countries. On a more general note, only 5 countries in the world have developed separate codes that specifically target traditional, vernacular or non-engineered construction techniques for remote and rural settings. These are India (IS13828-1993) and Nepal (NBC203-2015) but mainly for housing designs in low-strength masonry; China (JGJ161-2008) for seismic construction in rural areas; Peru (E.080-2017) and Morocco (RPACTerre-2013) for earthen structures.

2.3 Rubble Stone Masonry in Practical Manuals

In 2019 an extensive review was carried out on a total of 47 relevant field manuals for the period between 1972 and 2017, with regards to the design and construction of rubble stone masonry houses and schools in seismic areas [10]. An overview was created of similarities, contradictions, gaps and differences between all main design and construction requirements, and the publications were analyzed for eligibility as well as checked for compatibility with national building codes. The review concludes that the currently available technical information is perceived as highly confusing, contradicting and incomplete. Some of these conclusions are summarized in this section.

Out of 47 manuals, 28 were rejected for further review due to incompleteness and lack of clear definitions for the proposed types of buildings (schools or houses), types of stone masonry (rubble or Ashlar) or types of mortar (mud, lime or cement-based). From the remaining 19 manuals, 10 were specifically meant for house designs, and 9 included school buildings as well. Interestingly, almost all these manuals (17 out of 19) are specifically targeting the Himalayan context, whilst the Indian and Nepali codes prohibit school buildings in stone. Overall, just one manual was rated as being “complete”, but it must be clearly noted that this is no indication of the value of the provided information.

From the 9 manuals that describe school buildings, 7 are (co-)written by the same author and the available knowledge, which is largely based on empirical evidence, can be traced back to just a few main sources from the 1980's. These are the first ever published manual on the topic "Basic Concepts of Seismic Codes: Non-Engineered Construction" in 1980 [11], followed by the most referred-to manual "Guidelines for Earthquake Resistant Non-Engineered Construction" in 1986 [12]. In both revisions in 2004 and 2014 the chapter on stone masonry was copied to the letter, which indicates that the knowledge has not progressed much since it was first published. It is further noted that the same information and figures are copied repeatedly in almost all other publications, usually without references or fact-checking. This includes apparent conflicts between details, such as the key connections in t-sections as shown in figure 3. It is simply impossible to have both through stones and vertical bars in the same position, yet this mistake which first appeared in 1986 has not been rectified or properly solved in any manual in the past 30 years.

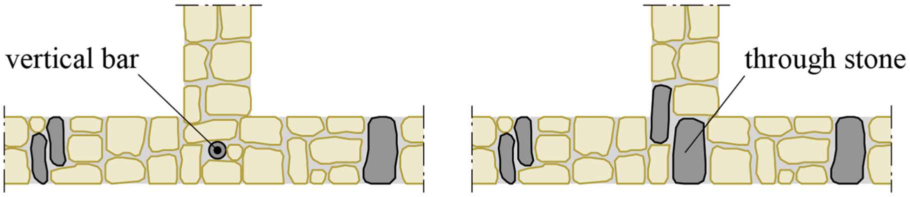

Figure 3 – Conflicting rubble stone masonry details of a) T-section with vertical steel bar and b) T-section with through-stones (by courtesy of Smart Shelter Foundation).

Moreover, given the fact that almost all knowledge comes from just one author, it is striking that no consistency nor consensus was found on almost all key elements, such as for main dimensions of buildings, wall elements and openings, nor for the inclusion of reinforcing elements. For school designs the number of allowed stories ranges from 1 to 4 floors, unsupported wall length between 5 and 9 meter, maximum percentage of openings between 30% to 50% and number of horizontal bands are introduced at 2 to 5 levels per story. The same inconsistencies are seen for the housing designs, which also show no adaption whatsoever to the requirements of the national building codes. This clearly shows in today's reconstruction efforts in Nepal as well. Despite the fact that the Nepali seismic code (NBC202-2015) does not allow stone masonry schools, exceptions are made when the design is prepared by qualified engineers and approved by the government, of which examples are published online by the Nepal Reconstruction Authority [13]. Figure 4 shows three examples of wall reinforcements in buildings, with an assumption of maximum 50% of openings per wall length. The current Indian code (IS13828-2008) only prescribes horizontal bands at lintel and roof level. A plinth beam is not required on hard soils, and when opening lengths exceed 42% these must be boxed. The Nepali code always requires bands at 4 levels (plinth, sill, lintel and roof) and stitches at intervals of 500 to 700 mm height. Boxing of openings however is not required when the total is less than 50%. Then why do all post-earthquake designs suddenly include stitches at 3 levels plus vertical posts, regardless of the percentage of openings? No justification was found for this excessive reinforcing, which is likely to increase costs and may even cause structural issues due to concentration of forces, as recent research at IIT Kanpur in India shows [14]. Yet somehow, this seems to have become the norm today.

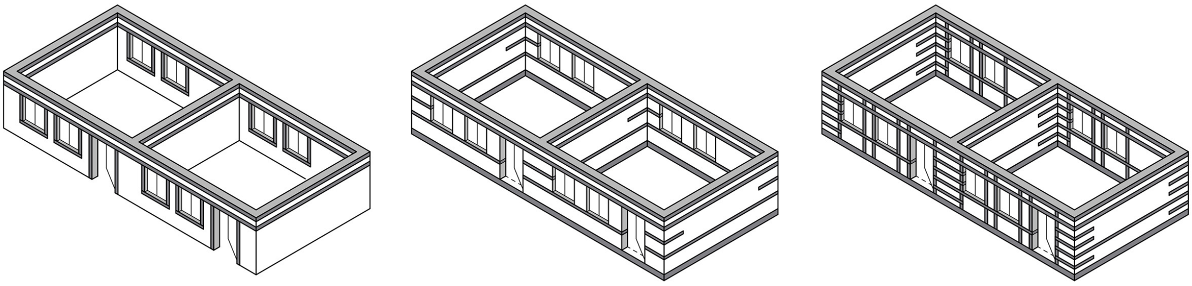

Figure 4 – Reinforcing of walls according to a) Indian code IS13828-2008, b) Nepali code NBC202-2015 and c) current practice today in Nepal (by courtesy of Smart Shelter Foundation).

3. Non-Engineered 2.0

When summarizing the previous chapter about traditional, vernacular and informal construction practices, it is concluded that the available information in the codes, technical regulations and practical manuals is largely outdated, contains many contradictions, and has become ambiguous. This raises questions about the completeness and correctness, as well as about the reliability and actual value of the knowledge. In order to progress and improve this situation, the following renewed philosophies, steps and solutions are proposed.

3.1 Acknowledgement

The first important step is acknowledgement of the current situation. We must truly ask ourselves if we are satisfied with the existing levels of knowledge and information. Have we progressed enough since the introduction of this knowledge 35 years ago? Do the empirical rules-of-thumb adequately address and fulfill today's needs for all different construction processes, contexts and settings? Are we offering reliable technical and practical solutions to all stakeholders, from the homeowners and self-builders, to the aid industry and governmental bodies? Have we done enough for the developing countries, in which the devastation is usually highest after earthquakes?

Surely, valuable work has been carried out over the years, but it is largely based on empirical evidence which has not advanced much since the 1980's. Overall, the techniques, dimensions and elements have been described, but too often in too general terms. However, basic questions such as applications in different seismic hazards, required number of beams, correct positioning of buttresses, or the need for vertical steel reinforcements have hardly surpassed the level of assumption and opinion. In-depth justification or scientific validation of how these elements really work and behave during a seismic event are basically not present. Whether this is possible to begin with and up to what level this is truly achievable remains to be seen. Perhaps the correct answers are already present somewhere in the literature, although momentarily buried under a pile of misinformation. Either way, somewhere along the way we seem to have lost our grip on the basics and if we continue to keep running around in circles, the knowledge level will certainly not progress. It will probably get worse given today's culture of copy-pasting and online sharing.

Acknowledgement is not an easy step, as this implicates that things have not been properly or sufficiently addressed in the past. We may even need to set our ego aside. But it is a vital step in order to break the current cycle and to mark a new starting point where we collectively agree that the current situation is no longer acceptable, and that we need to find new ways to move forward. We, the authors of this critical writing clearly acknowledge the need for renewed views and a drastic change of attitude, which requires full-time dedication and a structured, systematic and scientifically based long-term approach in order to significantly improve the seismic behavior of non-engineered techniques. The time has come for "Non-Engineered 2.0" and we invite you, the reader, to think along with us and join the upcoming research challenges.

3.2 Prioritization

A second important step is to prioritize and focus on the most urgent needs within the overall process. Or simply said, first things first. This writing is focusing on the technological side of the problem, as it is concluded that the technological level is currently not up to standard. On the other side we recognize the need for improvements towards dissemination of information, on-site training and code enforcement, which are not to be underestimated. But for as long as the knowledge has not reached acceptable levels, we wonder: What is there to disseminate in the first place? For us engineers, the primary responsibility and priority lies in improving the technology. Technology transfer, as the name implies, can only follow after.

Another prioritization should be safety over finance. The urgent need for cost-effective solutions is well-understood, given the tough economic situation in many places in the world. But we must accept that safety sometimes comes with a certain price. The Nepalese government has added a number of alternative and cost-effective construction types to their reconstruction catalogue (vol.II), such as gabion bands and sandbags [15]. Besides possible issues of cultural acceptance and practical implementation of such “alien” construction types, no seismic validation nor scientific justification has ever been presented so far. On the other hand, the inclusion of horizontal bands in traditional construction types is not that expensive, at around 1.5% per band of the total construction budget [16]. The price difference between cement and mud mortar however has a huge impact, but it may just be the difference between survival and collapse. These solutions also require further validation, but in any case, safe (and validated) solutions should be recommended over cheap (and unvalidated) solutions, regardless of the fact they can or will be followed on-site.

3.3 Documentation

Regarding the documenting of information, several improvements are proposed. During the review of practical manuals [10] it was noticed that the majority addresses the topic of non-engineered construction in a general way, by including chapters about different types of masonry, concrete frames, wood buildings and earthen structures all in the same document. The reader constantly must go back-and-forth between chapters about foundations, general masonry, reinforcements and roofing, and filter out the relevant lines for their particular technique of interest. This back-and-forth paging is not only time-consuming, it increases the risk that information is overlooked, and more importantly that information is misinterpreted, as it is questionable whether sizes, dimensions and details can be exchanged that easily between different techniques. Further issues with generalization were noted, being that most often no distinction is made between higher and lower seismic levels, nor between importance of buildings for schools or houses. Such general approach of these “one-size-fits-all” publications may result in either excessively reinforced houses in low seismic zones, or worse, in insufficiently reinforced important buildings in an area with high seismic hazard.

The review of building codes [6] including national seismic and masonry codes brought further issues to light. One thing is that they often refer to information that is printed outside the publication itself. For example, the Indian Standard for improving earthquake resistance of low-strength masonry (IS13828-2008) refers to different codes such as for foundations (IS1904-1989), zoning and building categories (IS1893-1-2002) and code of practice (IS4326-2005), which in turn refers to the code for Unreinforced Masonry (IS1905-1995), which in turn refers to the code of practice for rubble stone masonry (IS1597-1-1996). Between the first print of IS13828-1993 and the latest version of 2008, several amendments were added to the beginning of the document, which need to be replaced by the reader. Overall, this document has become very difficult to read and to interpret. And here as well we need to raise the question whether certain dimensions and specifications for thinner brick masonry can be freely interchanged with requirements for thicker stone walls.

To avoid all the above issues, it is recommended to prepare stand-alone documents for each technique separately. Adobe structures behave differently than wooden buildings, block and brick masonry is different from stone masonry, and it is also likely that we must distinguish between stone masonry with cement mortar compared to stone masonry with mud. It is further recommended to structure the national codes for non-engineered techniques in such way, that all necessary information can be found in one document. National codes should target engineers and experts and be made mandatory. Design and construction manuals should appeal to a wider audience of different user groups, but in all cases the information must be compatible and aligned with the national codes. Regardless of the status and type of publication, they should all be upgraded with clear descriptions of which exact technique is addressed, in terms of structural system, wall types, materials, units, mortar types and such. Clear distinctions must be made between different seismic hazards, soil classifications, building types and their implications. And for each scenario the complete design and construction sequences must be fully detailed, in order to ensure a successful implementation of the building. This should be based on information that is validated, correct and complete according to the current state-of-the-art, which brings us to the main challenges at hand.

3.4 Material Properties of Non-engineered Constructions

Already at the very beginning of the development of guidelines for seismically prone developing countries, Prof. A.S. Arya concluded the following in his paper for the 6th World Conference on Earthquake Engineering in New Delhi in 1977: “A review of the earthquake codes of various countries shows that much of the information is empirically based and not theoretically derived. In that respect the recommendations must be subject to continuous review and change as more data becomes available” [17]. Looking at the current state of the available information, Arya’s statement of 1977 still seems valid today and the key question remains: How can we accurately predict, and significantly improve, the seismic behavior of locally built traditional and non-engineered structures in earthquakes? This research question has not been adequately addressed by the engineering world to date, as local influences and site-specific parameters are not integrated in current calculations and models, and a methodology that includes such parameters inherent to traditional and informal building practices (e.g. local site conditions, material properties, workmanship and building quality) is currently non-existent.

The material properties and mechanical characteristics of conventional building techniques, such as concrete, steel and brick masonry, are well known. They have been researched for many years and tested extensively in lab facilities all over the world, following uniform test protocols. Also, in most parts of the world, strict building codes are in place and construction workers are properly trained, to ensure that buildings meet certain standards for quality and performance. This is not the case for a non-engineered technique such as random rubble stone masonry, especially in rural and remote areas. Here the local building practice is simply passed on from father to son, according to local customs and needs. The quality of construction is often substandard, as materials are scarce, financial means are low and building regulations are non-existent.

Such locally constructed technique is characterized by a high variety of material compositions and construction qualities, and therefore it is very difficult to find uniform and homogenous material properties of locally used mountain stones, cements and sands, and for their combined actions into mortars and masonry. Just imagine the following variables for any piece of rubble stone wall:
-Rubble stones can either be mountain stones, river boulders, conglomerates, sandstones, quartzite, schists, limestones and gneiss, among others.
-Sand comes from different rivers and can be categorized as very coarse, course, medium-graded, well-graded, fine and too fine. Also, contaminations and organic content must be considered.
-There are dozens of cement brands available in the market, with different grades, qualities, and 'freshness', highly depending on how the cement is stored and transported to the buildings site.
-Regulations generally describe mortars and concretes as mixed proportions by weight. On the building site however, rationing of ingredients is generally done randomly, or by volume at best, which in either way results in different (usually weaker) strengths than carefully balanced proportions by weight. Also, the method of mixing is of high influence, such as mechanically mixed versus hand-mixed with shovels. Academically tested data was not found on this particular subject.
-As the term random implies, the laying of stones in basically any pattern results in numerous variations. Added to this is the way of connecting the wall wythes, and detailing of corners, critical sections and around openings. Of further influence are thicknesses of joints, curing of walls, experience of the mason, climatic influences and so on.

If we take all the above factors into account, there are literally thousands of combinations possible, and it is impossible to test them all. Therefore, it is of utmost importance to detect those material properties that have the highest influence on the performance of rubble stone masonry. For which an innovative approach with workable and realistic scenarios must be developed to test those prioritized properties, which are highly influenced by local parameters and regional workmanship. This is one of the main objectives of the newly launched project named “SMARTnet”.

3.5 SMARTnet

The project SMARTnet, which stands for "**S**eismic **M**ethodologies for **A**pplied **R**esearch and **T**esting of **n**on-**e**ngineered **t**echniques", aims to update the knowledge of traditional techniques in general, and to gain a better understanding of the seismic behavior of rubble stone masonry buildings in particular. A second aim is to make this knowledge understandable and available for engineers and non-engineers all over the globe. Hopefully this strengthens confidence in those countries that still use this technique, as well as creates renewed interest in countries that currently prohibit it.

Main objectives of the project are to determine the Seismic Demand and the Seismic Capacity of three typical designs in rubble stone masonry as shown in figure 5. Two housing designs as published in the reconstruction catalogue after the Gorkha Earthquake in Nepal (vol.I) [18] and one small school building as built in Nepal by Smart Shelter Foundation are taken as representative case studies for full seismic analysis, structural improvement and cost reduction. The general structural engineering rule is followed: Seismic Capacity must be larger than Seismic Demand.

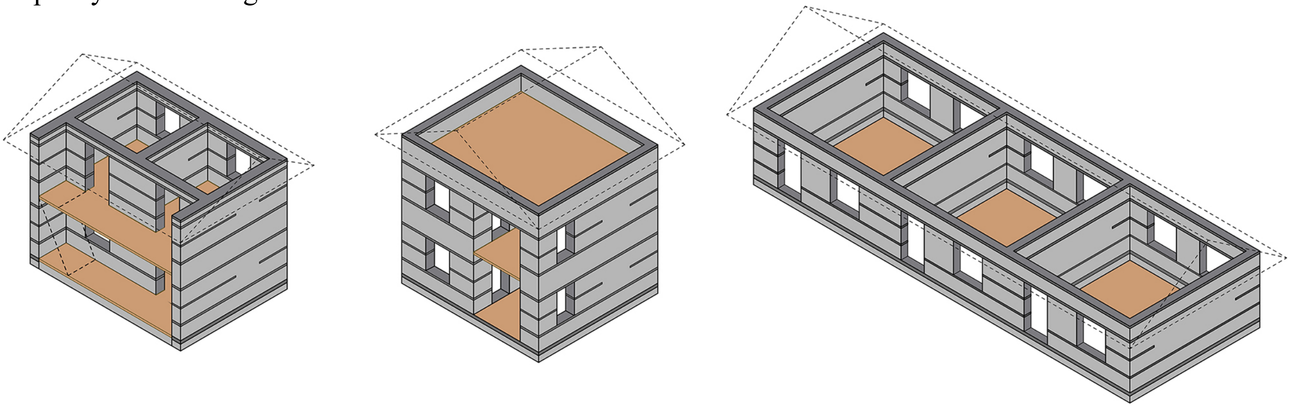

Figure 5 – Case study buildings as proposed in Nepal, being a) two-story slender house, b) two-story plus attic stocky house and c) three-classroom school building (by courtesy of Smart Shelter Foundation).

The Seismic Demand describes for instance the design requirements such as allowed typologies, dimensions, seismic features and detailing, as well as the structural and mechanical strength requirements of the stone masonry buildings and their individual elements. Hand-calculations for total base shear and distribution of seismic lateral forces over the buildings are being performed and seismic codes are compared for a selected number of countries where stone masonry is currently allowed, to determine their global Seismic Demand for different seismic hazards. This paper is meant to be online before 17WCEE starts [6].

To evaluate the Seismic Capacity of rubble stone masonry, we must have a good understanding of the collapse mechanisms and structural capabilities of the technique, as have been well described by Ortega et al [19]. It is presumed that out-of-plane failure is not likely to occur in our case study buildings, due to the continuous horizontal tie-beams which ensure good box-behavior. Further hypothesis is that buttresses are not needed due to limitation of spans, use of cement mortar, and improved bonding with through-stones in the walls. The focus lies on the mechanical and strength properties of materials, low-strength mortars and their combined actions into wall masonry. It is expected that the determination of bond strength between mortar and stone units is the most critical parameter, for which an innovative approach with workable and realistic "best and worst case" scenarios will be developed that integrates parameters for local materials and regional workmanship. To achieve uniform test results, overall test protocols based on American Standards (ASTM), Indian Standards (IS) and European Norms (EN) will be developed, specifically for testing of low-strength mortars and rubble stone masonry specimens. Basically, we aim to develop universal sets of test protocols for low-strength mortars and low-strength masonry in order to generate reliable material properties that can be used for calculations and computerized modelling.

Due to the large number of tests to be carried out, the project envisions a global and joint approach with involvement of inter-disciplinary universities and a high student participation. This is an important philosophy and main strategy in order to cross-check data and generate large outputs in the shortest possible time frame. As a further objective, the SMARTnet database application will be developed. This online platform will serve as a tool for communication between the stakeholders, exchange of knowledge, organizing of the research tasks, collection of data and open-source dissemination of results. During 17WCEE an international call will be placed to join forces and expand the network, in order to gain worldwide attention and to create global collaborations for tackling this huge challenge.

4. Conclusion

Extensive literature reviews of national seismic and masonry codes, as well as of practical design and construction manuals with regards to the technique of rubble stone masonry, show that the current available information is outdated, confusing and incomplete. The authors of this paper find this situation no longer acceptable and call for international acknowledgement of the situation. Fact is that millions of people will continue to live in stone houses in India, Nepal, Pakistan, Bhutan, Afghanistan, China, and likely in regions in Central Asia, the Middle East and Northern Africa as well. They need clear and reliable information that is up-to-date and complete. Therefore, the existing knowledge must be fully assessed, validated, optimized and complemented by means of the current state-of-the-art for calculating, testing and modeling. The time has come for an updated and structured research approach that specifically addresses vernacular and traditional construction techniques: “Non-Engineered 2.0”.

To achieve this, renewed philosophies and strategies are necessary, for which several recommendations and solutions are proposed. Once and for all the terminology must be clarified in terms of building typology, structural type, materialization and detailing, in order to be certain and clear what type of structure we are designing and analyzing. Therefore, this writing calls for adoption of a fourth type of masonry called Nominally Reinforced Masonry (NRM), next to the existing types of Unreinforced, Confined and Reinforced Masonry (URM, CM and RM). Furthermore, each separate type of construction should be fully described in all its facets and sequences of design, calculation and implementation, which should be presented in stand-alone publications. National norms must be mandatory, and the design and construction manuals must be compatible and aligned with these national codes.

Three designs in rubble stone masonry as built in Nepal will be fully assessed and validated, following the general structural principle that the Seismic Capacity must be larger than the Seismic Demand. As for seismic Demand, base shear calculations are made according to the seismic codes of a selection of countries from all over the globe, where stone is still used, or potentially could be used. In terms of Seismic Capacity, the key lies in the determination of reliable material properties with the inclusion of variables for local material quality and workmanship. For which workable scenarios of best and worst cases must be defined and uniform test protocols will be developed with focus on low-strength mortars and masonry.

All the above comes together in the newly launched project by the name of SMARTnet, which stands for “**S**eismic **M**ethodologies for **A**pplied **R**esearch and **T**esting of **n**on-**e**ngineered **t**echniques”. It is realized that the challenge is huge and the scope of work enormous, for which help is needed. The renewed strategy of SMARTnet envisions a joint approach of global collaboration, in order to cope with the massive number of variables and to generate cross-checked data that can be used for calculations and computer modeling of non-engineered techniques. This philosophy should be equally applicable to other techniques, such as earthen structures, traditional stone and wood buildings, as well as confined masonry. SMARTnet therefore places an international call for collaboration (including during 17WCEE), and invites experts, professionals, academics as well as final-year students in these fields to exchange their knowledge and to support the project with their time and expertise. All this, with the ultimate goal of reducing of loss of life, as well as reducing of financial losses in seismically prone (developing) countries, by reducing risk of damage and collapse of indigenous, traditional, and non-engineered buildings.

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