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8. Building Stones - application, suitability, research

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8.1

Geological methods in everyday conservation of monuments and sites

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Investigations in the field of conservation of heritage buildings and historic sites are manifold. They can be classified into five groups:

- analysis of original materials,
- analysis of degradation products,
- characterization of the interactions between the building materials and environment prevailing at the monument or the site in question,
- estimating the compatibility between the original materials and the conservation materials
- optimizing the treatment methods or the preventive conservation measures.

The naturalist approach and some simple methods commonly used by geologists are an essential basis for these investigations and generally provide practical results quickly acquired and useable.

Among these methods, field observations are crucial. Sometimes accompanied by mapping materials and degradations, they allow locating the problems, to draw up the state of conservation and to establish an initial list of potential causes of degradation. They allow also to determine what methods of investigation are most relevant in the studied case and to intelligently select the shape, size and locations of sampling when it is needed.

Samples from one to a few cubic millimeters may be sufficient to make observations of dispersions with polarizing light microscopy. These observations, together with microchemical tests extensively used in the early 20th century (Chamot & Mason, 1989) and then adapted by the Swiss geologist Andreas Arnold (1984), are a useful tool to identify the nature of soluble salts responsible for damage or to identify the mineralogical nature of the pigments of wall paintings and polychromies (Plesters, 1956).

On samples from one to a few cubic centimeters of natural stone or mortar the classical mineralogical identifications by means of thin sections can be made (Bläuer & Küng, 2007). But the analysis of a thin section also provides significant information on the form and distribution of pores of the stony materials.

Samples from ten to several tens of cubic centimeters are needed for petrophysical measurements (total porosity, capillary porosity, water absorption and drying kinetics, hydric and hygric dilation, characterization of the hygroscopicity and permeability to water vapor, ...) that characterize the building materials and the conservation materials (Jeannette 1997).
These petrophysical measurements allow us also and especially to determine the physical compatibility between the original materials and the conservation materials (Rousset et al., 2005). This can be tested e.g. by determining the ability of liquid water and vapour to pass from one material to the other, or by trying to find the optimal conditions for a conservation treatment by determining the optimal amount of product to be applied to get the desired result while avoiding as much as possible side effects due to too drastic changes of physical and mechanical properties between the treated and not treated areas.

Based on case studies, we show how we use these geological methods regularly as a part of our consulting activities.

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8.2

The use of ornamental stones from Arzo (Ticino) in the italian architecture

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Three different stones, called Broccatello, Macchiavecchia and Rosso di Arzo, were quarried in southern part of Canton Ticino. The stones belong to a Mesozoic sedimentary series outcropping in a large area from lake Maggiore to lake Como (Bernoulli 1964). Broccatello, a bioclastic micritic limestone, together with Macchiavecchia, a syngenetic breccia (Sinemurian, Lower Jurassic) pertaining to the "Lugano swell", outcrops south of lake Lugano close to the Italian border. Broccatello is purple-red with skeletal grains (Brachiopoda, Crinoidea) and some grey veins, Macchiavecchia is multicoloured with white calcite veins on a red, grey or yellow ground, Rosso is dark red with white calcite veins. All the stones are perfectly polishable.
The Arzo quarries are located north-east of the village and they are connected with the italian quarry area of Viggiù, Brenno and Saltrio whose brown or grey clastic limestones were quarried since the Roman times.
The Arzo "marbles" were widely used as ornamental stones either locally or in Northern Italy and in many other italians towns. The first use of Arzo marbles for architectural purpose probably dates back from the 13th century (cut stones for the piers of Broletto, Como) or for ornamental purpose from 15th century, as seen in a milanese church (St Maria delle Grazie - portal of Sacrestia vecchia, 1499). But it's difficult to ascertain the exact year of the marble setting because of the multiple remakes or restorations carried out on the buildings. A witness brought by Vasari in his book (1568) where two Macchiavecchia columns of the Medici funerary monument (sculptor Leone Leoni, Milan Duomo, 1560-63) were described as made of "*pietra macchiata simile al diaspro*" [a spotted stone like jasper]: so the Macchiavecchia was unknown to the Author.
The Macchiavecchia, on the contrary, was well known by Scamozzi, about fifty years later, and it was compared with roman coloured marbles. Scamozzi wrote in his architectural treatise (1615): "*Hanno parimente in Lombardia quella sorte di misto di color*

canellato, e verdiccio corneo più bello di quello della Porta Santa di Roma" [They also have in Lombardy a stone mixed brown to greenish in colour, nicer than the Portasanta in Rome]. The Portasanta is a brecciated limestone from Hios island (Greece) widely used by the Romans for flooring and wall veneering and reused for the enframements of the Porta Santa (Holy Door) of St Peter basilica (early 17th century) in Rome. So the Arzo marbles replaced the roman coloured ones whose quarries were unreachable for a long time.
The Arzo marbles were almost entirely devoted to the altar ornamentations for more than two centuries (17th and 18th). The construction of new altars in the churches was supported by the liturgical renewal in consequence of the Tridentine Council (1545 - 1563). Generally the Arzo marbles were mixed with different coloured marbles coming from Lombardy and from abroad: Arabescato orobico, red and grey limestone from Val Brembana (Bergamo); black limestone from lake Como (Varenna - Lecco); *Occhiadino*, grey and white limestone from Val Camonica (Brescia); white marble from Apuanian Alps (Tuscany); *Rosso di Francia*, red and white limestone from Aude department (France) and few others. The use in the course of the centuries was ubiquitous in milanese churches (St Alessandro, St Ambrogio, St Lorenzo, etc.) and it's very well illustrated in the Duomo: the baptistery (architect P. Tibaldi, 1580), different altars and the crypt (also by P. Tibaldi, end of 16th century), the St Carlo funerary chapel called Scurolo (1606), the St Giovanni Bono altar (late 17th century), the mixed marbles flooring (18th century), the crypt vestibule (1810), the high altar (1985). The marbles were used as: column shaft (monolithic, maximum length about 3 metres, Macchiavecchia), moulding (Macchiavecchia), balustrade (Macchiavecchia, Rosso), veneering or inlay (Macchiavecchia, Broccatello) and flooring (Rosso).
The inlay was made of thin slabs (about 1 cm thick), sometimes in different pieces with curved cuts to enhance the colour variegation and to counterfeit a monolithic slab. Each slab was placed in a shallow pocket carved into the main material (black limestone or white marble) and fixed by an adhesive made of different components as colophony, turpentine, beeswax, etc. mixed with quartz sand or crushed marble.
The marbles were also used in civil buildings, mainly in the balustrades of the main staircases of palaces: Litta (Milan, 1740), Affaitati (Cremona, 1769), Villa Olmo (Como, 1782-97). At least, another important use includes furniture (flat slabs for tables or consoles) and fireplace (Villa La Gallia, Como).
The geographical extent of the use of Arzo marbles was wide; the following list, based on direct observations, is significant but incomplete. Canton Ticino: Arzo, Ascona, Bissone, Brissago, Ligornetto, Locarno, Lugano, Mendrisio, Riva San Vitale. Lombardy: Bergamo, Breno, Busto Arsizio, Cairate, Carpiano, Castelleone, Como, Legnano, Lodi, Melegnano, Morbegno, Pavia, Saltrio, Saronno, Vezza d'Oglio, Vigevano, Viggiù, Villa Pasquali. Piedmont: Aosta, Baveno, Ivrea, Novara, Turin, Varallo. Venetian: Venice. Emilia-Romagna: Bologna, Ferrara, Parma. Liguria: Genoa. Latium: Rome. Campania: Cava dei Tirreni, Neaples.
The decline of these altar ornamentations, called "architectural absurd" by Francesco Milizia, involved the decline of Arzo marbles in the 19th century. But some important accomplishments are still present in Milan: the columns of St Giorgio al Palazzo (1800-21); the basement of the St Simpliciano high altar (1835); the portal of St Carlo al Corso (1839-47); the columns in the atrium of Bagatti - Valsecchi palace (1878). The Arzo marbles were thereafter reported by the architecture and marble treatises in this century, despite their foreign provenance: Milizia - Antolini (1817), Amati (1830), Stoppani (1857), Curioni (1877) and Salmojraghi (1892).
The Arzo marbles were mainly referred to the inside use, so the state of conservation is generally good. But these coloured marbles exposed to weathering are always affected by surface roughening and chromatic alteration. The first one is caused by rain washing dissolving the calcite crystals; the second one fades the colourful surfaces turning them to a brownish or pinkish hue. An example of these decay phenomena are the Macchiavecchia elements in the columned portal of St Maria dei Miracoli (Milan, late 16th century) and in the portal of Monastero Maggiore (Milan, 1683).

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8.3

The natural stones used on the Romanesque north wall of the St. Martino church in Mendrisio

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The Romanesque north wall of the St. Martino church in Mendrisio (fig. 1) has been chosen as model for an applied research project called OSMATER (http://istgis.ist.supsi.ch:8001/osmater/) aimed to link the original materials used, the quarries and the possible routes.

Irregular scabbled stones of silicified limestones have been largely used for the wall corresponding to the oldest one. This stone is locally called Pietra di Salorino (Salorino stone) being the village part of the mining district.
The upper part of the wall is decorated with small arches in Travertine called Tufo Lombardo (Lombard Tuff). The final cornice is in individual decorated blocks of sandstone.

The correlation between the microstructure and the composition of the raw materials and the stones used on the wall allows to refer the silicified limestone to the quarry located at Monte Casima close to the Salorino village and the church. The rock belongs to the Moltrasio stone formation (Low and Middle Lias). It is a marly limestone, pale grey in colour, with veins filled up with coarse grains of calcite and nodules of flint.
The Quaternary Travertine is locally called Tuff for its analogies with the volcanic rocks. The petrographic examination allows to refer this material to the Travertine deposits located in Rancate, a village close to Mendrisio.
The sandstone belongs to the formation Conglomerate of Como (Oligocene); it comes from the quarries located in Malnate and is locally known as *Pietra Molera*. The colour ranges from grey to greenish, the grain size from medium to fine, the mineral phases are quartz, feldspars, biotite and muscovite. Grains of metamorphic and carbonatic rocks are also present. The matrix is siliceous.
The source of the silicified limestones and the travertine is just close to the building. The sandstone quarry is a little bit far from the church.

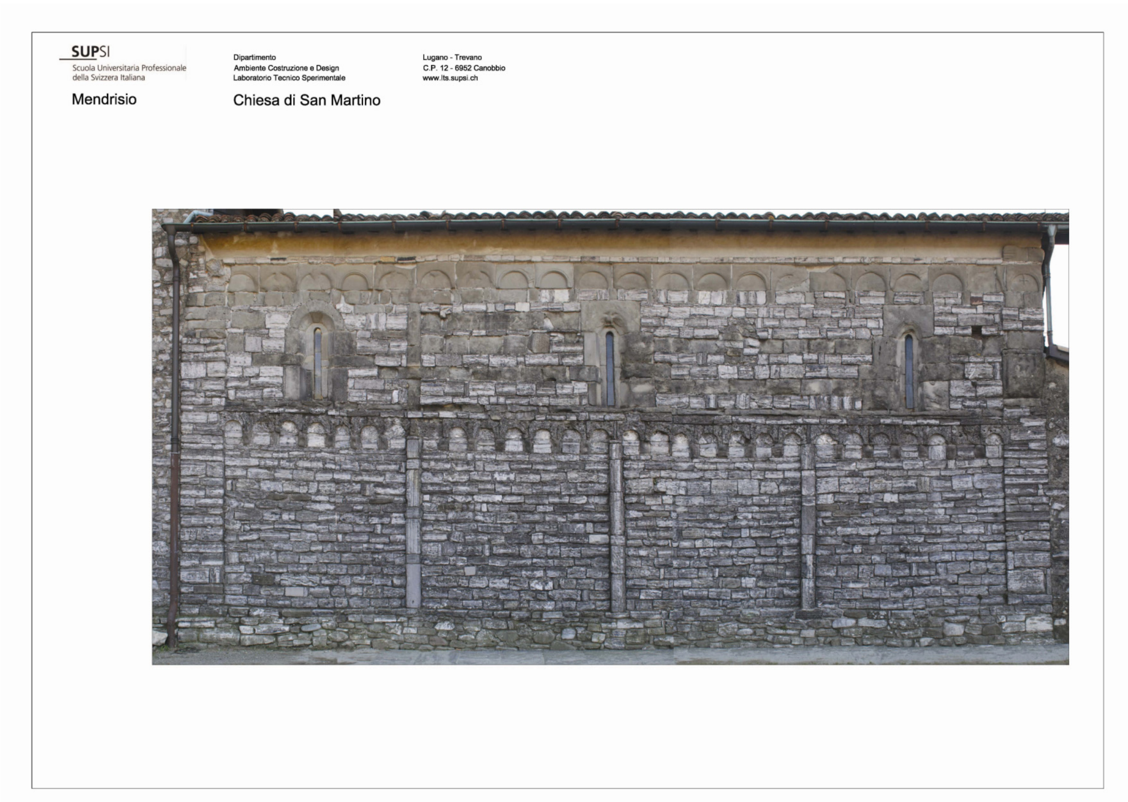

Figure 1. The Romanesque north wall of the St. Martino church in Mendrisio (orthophoto).

8.4

The soapstone of the Romanesque church of San Nicolao in Giornico, Canton Ticino (Switzerland)

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The Romanesque church of San Nicolao in Giornico is well known for its architectural and decorative elements made of soapstone and has therefore been chosen for an applied research project called OSMATER (http://istgis.ist.supsi.ch:8001/osmater/) which is dealing with the provenance (quarries) and the transportation routes of stones used for constructions in the past.

First of all a mapping of the soapstone present on external and internal parts of the church has been established. Apart from the sculpted consoles and capitals of the crypt and of the main and side entrance, soapstone has been used for four animals situated at the bottom of the western facade. Parts of the entrance arches, the blind arches and the window frames, as well as the large hexagonal baptismal font and a round holy water stoup inside the church, are also made of soapstone. The next step consisted in trying to characterize macroscopically the soapstone in situ and to establish a classification of different types of soapstone, following and comparing with studies performed on soapstone of the Canton Ticino. Subsequently small samples of every macroscopically established type of soapstone have been taken and examined by means of polarizing microscopy.

The preliminary results revealed that the macroscopically established types of soapstone did not fit the microscopical characteristics. Hence the primary concept consisting in establishing first the type(s) of soapstone and afterwards searching specifically for possible cave(s) of provenience by means of existing literature did not work. As sampling of soapstone from historical monuments is very restricted if at all possible other potential analytical techniques have to take into consideration to get information about its provenance.

Figure 1. Lower part of western facade with main entrance of the San Nicolao church in Giornico. The soapstones are marked with red colour.

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8.5

Spatial and temporal evolution of physico-chemical properties of polymer-modified mortar at the interfaces of large-sized tiles

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A basic setup for dynamic and spatially resolved investigations of microstructures at the tile-mortar interface of large-sized tiles was described by Wetzel et al. (this volume). In addition, spatially resolved shrinkage and adhesion measurements over sample series allow to reconstruct the evolution of the mortar-tile system. Results indicate that spatially resolved adhesion strength differs from medium values in the centre of the tile over maximum values in-between core and rim reaching minimum values in the vicinity of the rim. This relationship between strength and location was consistent over the entire hardening time. After 6 weeks, a belt of delamination formed few cm away from the rim and grows thenceforward. Dimensional variations of concrete substrate and tile were measured during mortar hardening over a broad mesh and showed differences from tile to substrate. Such variations may affect shear-stresses and its distribution in the mortar, a fact that is critical for local material failure owing to fracturing. The results of this study confirm the typical field observation of tiles, which are only bounded in the centre region and are loose at the edges – a critical situation in the evolution of a potential damage.

8.6

Setup for investigations of tile-mortar interface of large-sized tiles

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In order to reduce the risk of damages, the outdoor application of large-sized fully vitrified ceramic tiles asks for high quality mortars. However, dry-wet, freeze-thaw and hot-cold cycles lead to local cracking of the mortar-tile interface, which in certain cases can result in complete failure. The purpose of the research program (a collaboration of Elotex with the University of Bern, the Empa Dübendorf and CTI the Swiss Commission for Technology and Innovation) is to unravel the evolution of microstructures and the resulting material properties. Here, we describe the basic setup, which allows (i) the reproducible application of large-sized tiles (30 x 30 x 0.8 cm) and (ii) the systematic imaging (through glass tiles) of different aspects such as wetting (mainly as a function of trowel geometry and skin formation), drying, cracking and water ingress. By a quadratic light frame the glass tiles are illuminated from all four sides. This allows to contrast and image microstructures at the mortar-tile interface and to perform in-situ observations as a function of time and distance from the rim. First results of such dynamic studies in combination with the spatially resolved evolution of adhesion strength are presented by Wetzel et al. (this volume).

8.7

Stones on historic buildings and artworks of Switzerland – actual stage of the database

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The database "Stones on historic buildings and artworks of Switzerland" compiles petrographic and geologic information of the built heritage. It has been collected by Francis de Quervain from the 1950's to the 1980's (F. de Quervain 1983/84; a short presentation of the project was given at the Swiss Geoscience Meeting 2007). The database structure is shown in Figure 1. Presently about 50% of the data (covering the cantons AG, BE, BL, BS, FR, GE, JU, NE, SH, TI, VS, ZH) has been implemented, i.e. about 2500 objects (buildings and sites), 5000 sub-objects (building parts), 230 rocks and 1000 proveniences. Figures 2 and 3 give an example of analysis by geographic distributions of particular rocks on historic buildings. It is important to keep in mind that this information does not represent a statistical distribution. Rather is it an intentional selection which has focused on prominent, typical or easily accessible buildings and works of art. The aim of providing this information in a database is to republish it in an modern way. As a consequence, it can be used more extensively. That will help to better understand and maintain the monuments. It is also intended to update and supplement de-Quervain's collection by new data from various sources. Thus new data can be linked to old data, and architectural or historical information can be related to geographic, petrographic and geologic data in a local as well as in a broader context.

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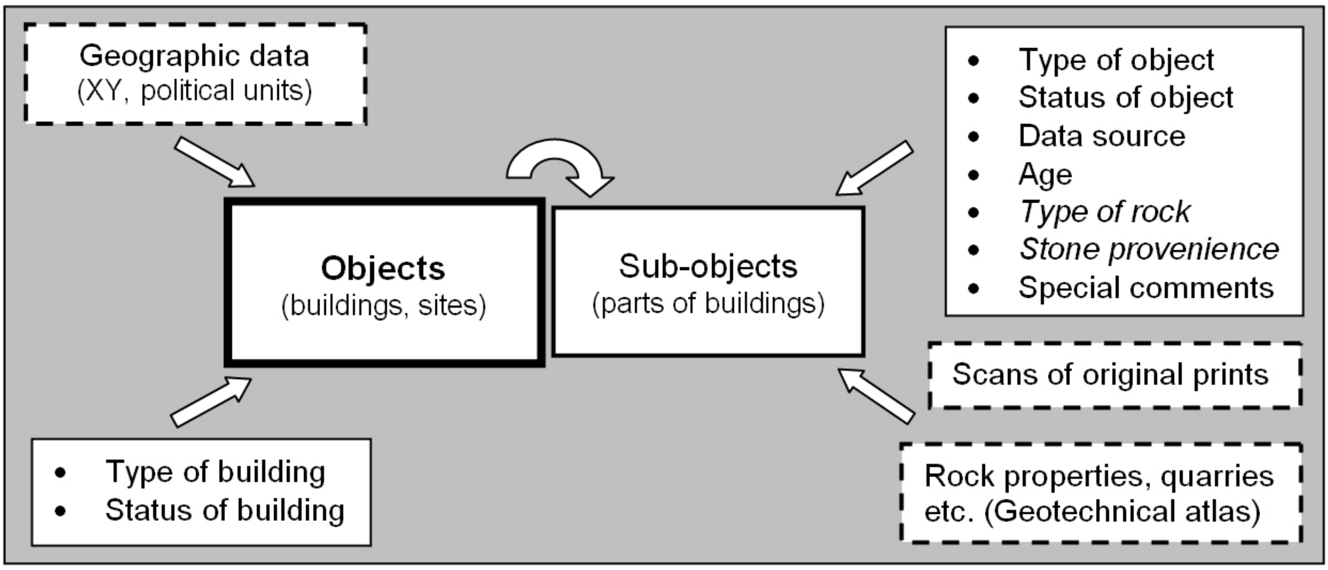

Figure 1. Schematic database structure. The table of georeferenced objects (buildings, sites) is central. It is linked with a sub-table of the relevant building parts and with further tables of specific data, such as rock type etc. Boxes with dashed outlines indicate related data sources and external information.

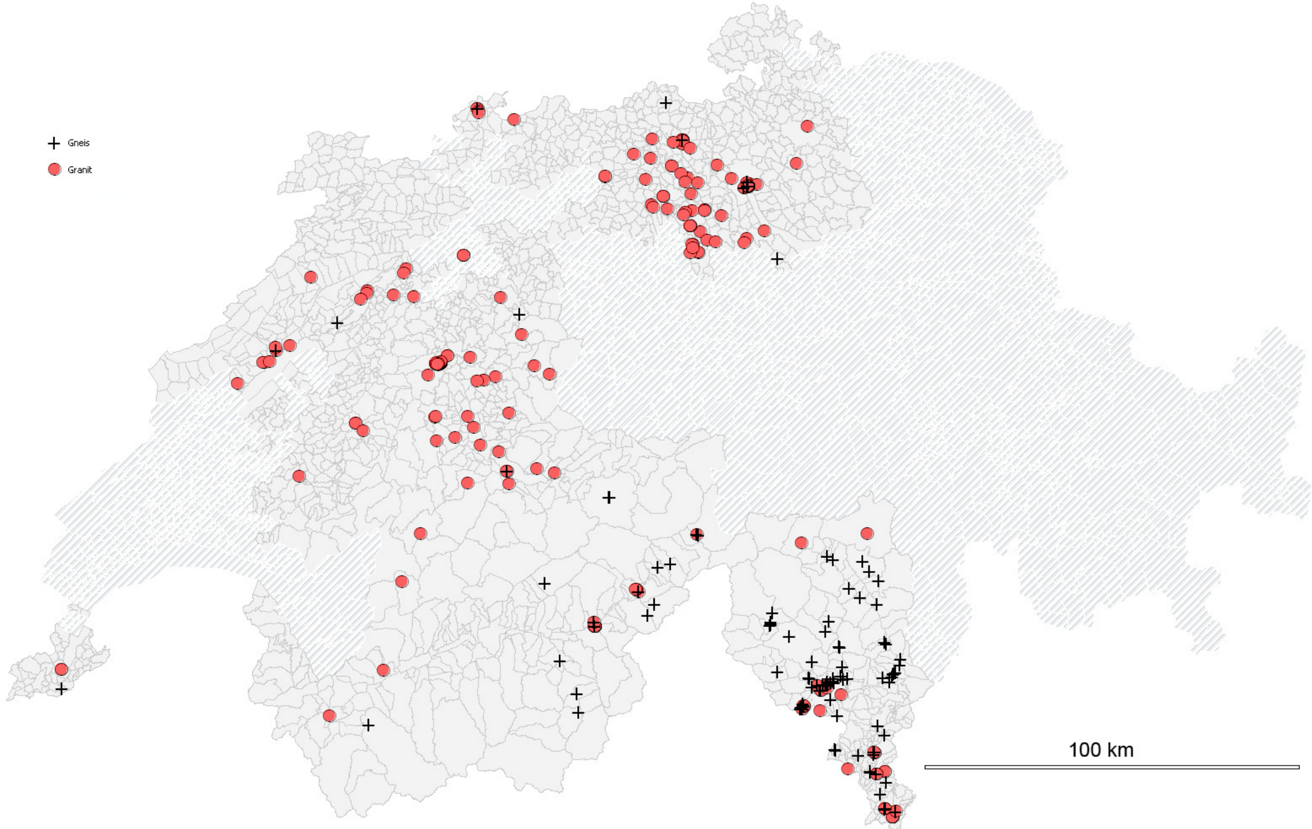

Figure 2. Example of spacial distribution of stones used on historic buildings in Switzerland. Generally, the distribution corresponds to the local and regional availability of stones, i.e. to the nature of the bedrock. In this example, granite (circles) relates to moraines in the northern part of Switzerland and gneiss (crosses) to local debris in southern parts of the Alps. Hatched area is not yet implemented in the database.

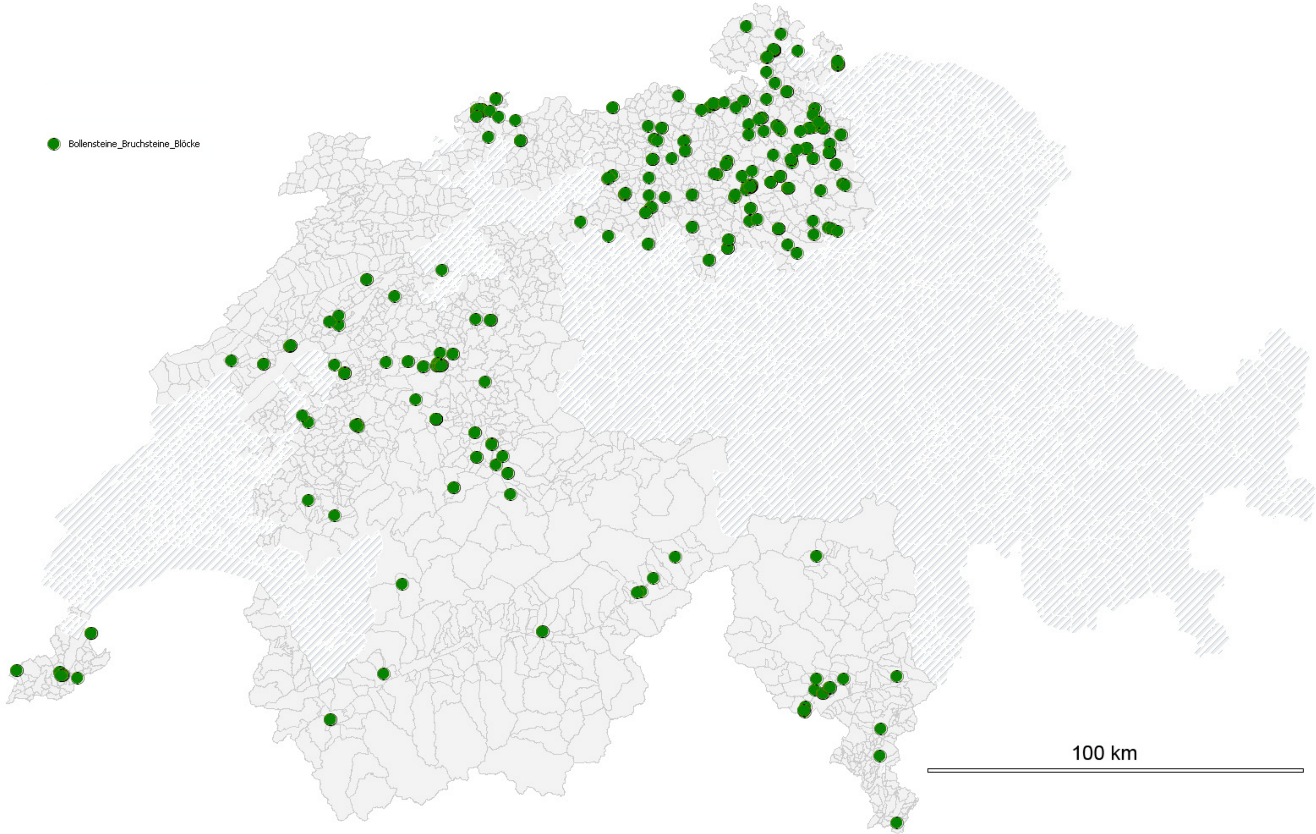

Figure 2. Pebble and rubble stone is widely used in the Alps as well as in surrounding areas according to abundant neogenic sediments of moraines and rivers.

8.8

Construction en pierre massive en Suisse. Le cas des Tre Valli au Canton du Tessin.

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L'intervention porte sur le projet "La Via della Pietra", réalisé à l'EPFL en 2006 et successivement développé pour la Comunità della Riviera. En particulier, on traite de la conception d'une auberge de deux étages et d'un atelier d'expérimentation situés dans la commune de Lodrino. Le système constructif de ces bâtiments est constitué par des éléments en gneiss de 2,2x1,1x0,55m (voir Figure 1).

La méthode choisie se base sur une approche globale au matériau "pierre naturelle": de la ressource jusqu'à sa mise en oeuvre.
Les études géologique, pétrographique et des caractéristiques techniques des roches des Tre Valli, basée sur des sources documentaires (Niggli et al. 1915, Kündig et al. 1997) et sur les informations fournies par les entreprises, ont permis d'établir leur aptitude à l'application structurelle massive.
La connaissance directe de la carrière contemporaine et des techniques d'extraction et de transformation est la base pour une nouvelle stéréotomie qui vise à la production d'éléments modulaires de grandes dimensions. La préfabrication, toujours présente dans le monde de la pierre naturelle, peut aujourd'hui devenir une des clés pour la valorisation de ce matériau de construction.
L'utilisation d'éléments massifs permet d'exploiter des pierres de qualité jugée aujourd'hui inférieure, ce qui est en accord avec une gestion durable de la ressource tendant vers une utilisation totale des matériaux extraits (Dino & Fornaro 2005).
Le développement des solutions constructives répond à un certain nombre de contraintes dont les principales sont celles liées au confort intérieur, à la résistance de la structure en cas de séisme et à l'établissement d'éléments modulaires issus des blocs extraits. Les choix opérés au niveau des détails de construction, de la physique du bâtiment et de la conception de la structure sont présentés ainsi que leurs vérifications.

L'étude ici présentée se situe dans le cadre d'une recherche soutenue par le Fond National Suisse de la Recherche Scientifique visant à démontrer la possibilité actuelle de réaliser des structures porteuses en pierre massive (*Construction en pierre massive en Suisse*, FN-100012-176509).

L'utilisation de matériaux locaux pour la construction est une nécessité non seulement pour réduire l'énergie grise des mêmes, mais aussi afin de favoriser le développement économique et social régional ainsi qu'un plus grand enracinement des bâtisses dans le territoire.
Ce mode de construction, dans un pays comme la Suisse où la pierre naturelle est une ressource disponible, permettrait d'un côté sa valorisation et de l'autre de participer à la sauvegarde de ce secteur économique.
La pierre naturelle comme matériau de construction est aussi un sujet de recherche qui, en Suisse, est désormais en déclin.

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Figure 1. Détail de la façade Sud du bâtiment projété à Lodrino.