Proposal Number: 285463 SUS-CON CP-IP

Sustainable, Innovative and Energy-Efficient Concrete, based on the Integration of All-Waste Materials

Deliverable D6.2
Fully operational prototypes

Author(s):	***Magnetti Building Spa***
Date:	***30 March 2015***
Workpackage:	WP6
Distribution[1]	PU
Status[2]:	***Final***
Abstract:	This work defines the exact number and specifications of prototypes to be evaluated and the types and number of validation tests.
File Name	***Deliverable D6.2***

1 PU: Public, RE: restricted to a group specified by the consortium CO: Confidential, only for members of the consortium; Commission services always included.

2 Draft, Revised, Final

Table of Content

1. Introduction

1.1. General

The main objective of WP6 is to validate the feasibility of the developed production process of the SUS-CON components and to demonstrate the real improvements in the component performances, with the aim of the subsequent industrialization. Fully-operational prototypes will be designed and realized, using the SUS-CON mixtures developed in WP4 and the product design and manufacturing methods developed in WP5.

The outcome of this task are prototypes for both ready-mixed and pre-cast concrete methodologies; they will be fully representative of both the industrial production issues and of typical energy-efficiency requirements and will be validated to show the conformities of the prototypes to their technical and functional statements.

The results will be used for product certification and the decision-support tool to be developed in WP8. A technical-economical analysis will lead to obtain fundamental inputs for the market exploitation analysis of WP9.

In the Task 6.2 (*Prototypes design and realization*) the exact number and specifications of the prototypes have been defined, together with the exact types and number of validation tests. This has involved the definition of test set-ups and of the performances to be tested: fire behaviour, mechanical resistance, thermal insulation and acoustic insulation.

The prototypes were chosen in such a way to be fully representative of both the industrial production issues and of typical energy-efficiency requirements. The dimensions of the prototypes were defined depending on the requirements of each test to be carried out.

For each prototype realized with the concrete developed in the project, a control one will be realized, made by traditional concrete and traditional design methodology and having the same specifications, in order to perform a significant benchmark.

1.2. Content of the report

This report consists of 3 chapters. Their contents are described below:

Chapter 1 - Introduction.

Chapter 2 - Prototypes characterization.

Chapter 3 - Description of the test and reference standards.

2. The prototypes characterization

The characterization tests to be carried out in order to evaluate the performances of the prototypes are the following:

- ✓ ***fire behaviour***;
- ✓ ***thermal insulation***;
- ✓ ***acoustic insulation***;
- ✓ ***mechanical (flexure) tests*** up to failure;
- ✓ ***thermal bridges*** by thermography.

For each test a reference partner has been defined; more in details:

- ✓ ***fire behaviour*** (carried out by Magnetti);
- ✓ ***thermal insulation*** (carried out by Magnetti);
- ✓ ***acoustic insulation*** (qualitative evaluation carried out by Cetma);
- ✓ ***mechanical (flexure) tests*** up to failure (carried out by Consorzio TRE);
- ✓ ***thermal bridges*** by thermography (carried out by Cetma on one demo site).

The following table summarizes informations about prototypes characterization (type of test, type of element, dimensions, number, for each type of characterization tests):

Test	Element	Prototype dimension	Number of test	Comparison
Fire behaviour	panel/masonry block	3 x 3 mt	2 + 2	standard / SUSCON
Thermal insulation	panel/masonry block	1 x 1,5 mt	3 + 3	standard / SUSCON (repeatability 2)
Acoustic insulation	panel/block	50 x 50 x 5 cm	2 + 2	standard / SUSCON
Mechanical test	panel	4,5 x 2 mt	3	standard / SUSCON (repeatability 2)

Table 1 Prototypes and relevant test to be performed

For each test the number and size of the prototypes to be tested was defined; more in details:

- ✓ for ***fire behaviour*** test 4 prototypes of size 3 x 3 m will be tested, including 2 tests with standard concrete and 2 with SUS-CON concrete;
- ✓ for ***thermal insulation*** test 6 prototypes of size 1 x 1.5 m will be tested, including 3 tests with standard concrete and 3 with SUS-CON concrete;
- ✓ for ***acoustic insulation*** test (only qualitative test) 4 prototypes of size 50 x 50 x 5 cm will be tested, including 2 with standard concrete and 2 with SUS-CON concrete;
- ✓ for ***mechanical test*** 3 prototypes of size 4.5 x 2 m will be tested, including 1 with standard concrete and 2 with SUS-CON concrete.

3. Description of the test and reference regulations

Hereinafter the characterization tests that will be carried out are described highlighting the reference standards.

3.1. Fire behaviour

The purpose of this test is to measure the ability of a representative specimen of a non-loadbearing wall to resist the spread of fire from one side to another.

It is applicable to non-loadbearing walls, with and without glazing, non-loadbearing walls consisting almost wholly of glazing and other non-loadbearing internal and external non-loadbearing walls.

For external fire exposure to a non-loadbearing external wall, the external fire exposure curve given in EN 1363-2 is used.

The test specimen shall be installed in the test frame and, if used, the supporting construction, as in practice.

The test specimen shall be mounted as near as possible to the exposed vertical plane of the test frame or supporting construction as appropriate, unless in practice a different position is used.

The whole area of the test construction shall be exposed to the heating conditions.

3.1.1 Thermocouples

Plate thermometers shall be provided in accordance with EN 1363-1. There shall be at least one for every 1.5 m^2 of the exposed surface area of the test construction. The plate thermometers shall be oriented so that side ‘A’ faces the back wall of the furnace.

For walls with an anticipated insulation performance in excess of 5 mm, thermocouples of the type specified in EN 1363-1 shall be attached to the unexposed face for the purpose of obtaining the average and the maximum surface temperatures.

3.1.2 Average temperature

a) Uniform non-loadbearing walls

For test specimens which are uniform with respect to their expected thermal insulation, the average temperature of the unexposed face shall be measured by means of five thermocouples, one located close to the centre of the specimen and one close to the centre of each quarter section.

b) Non-uniform non-loadbearing walls

For test specimens of non-uniform non-loadbearing walls, i.e. those which contain discrete areas 0.1 m^2 expected to exhibit different levels of insulation performance e.g. glazing, each discrete area shall be individually monitored for average temperature rise. The average temperature rise shall be measured by thermocouples distributed over each discrete area. One thermocouple shall be provided for every 1.5 m^2 or part thereof of the specimen. A minimum of two thermocouples for each discrete area shall be provided.

3.1.3 Maximum temperature

For determination of maximum temperature thermocouples shall be applied to the unexposed face as follows:

a) at the head of the specimen at mid-width.

b) at the head of the specimen in line with a stud mullion.

c) at the junction of a stud and a rail in a non-loadbearing wall system.

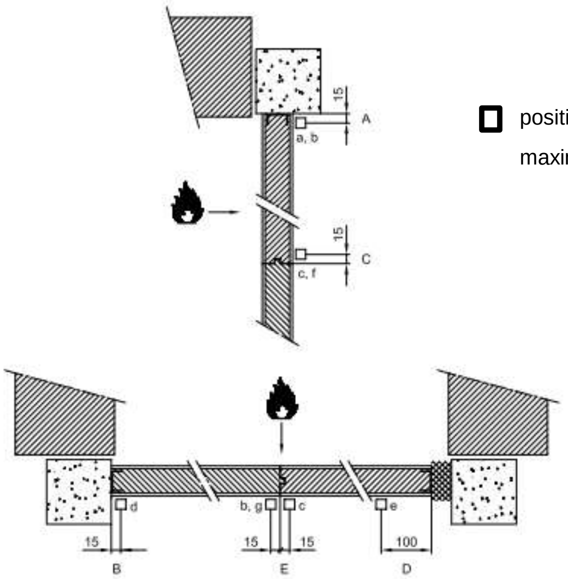
d) at mid height of the fixed edge.

e) at mid height of the free edge, 100 mm in from the edge.

f) at mid width, where possible, adjacent to a horizontal joint (positive pressure zone).

g) at mid height, where possible, adjacent to a vertical joint (positive pressure zone).

Thermocouples for evaluating insulation shall not be positioned closer than 100 mm from any discrete area that is not being evaluated for insulation.



position for thermocouples for maximum temperature rise

Figure 1 Example of application points of the not exposed thermocouples in the prefabricated panels

3.2. Thermal Insulation

Evaluation of the thermal insulation of the concretes will be carried out according to the standard *EN ISO 8990.*

Many thermal insulating materials and systems are such that the heat transfer through them is a complex combination of conduction, convection and radiation. The methods described measure the total amount of heat transferred from one side of the specimen to the other for a given temperature difference, irrespective of the individual modes of heat transfer, and the test results can therefore be applied to situations when that is the property required. However, the thermal transmission properties often depend on the specimen itself and on the boundary conditions, specimen dimensions, direction of heat transfer, temperatures, temperature differences, air velocities, and relative humidity. In consequence, the test conditions must replicate those of the intended application, or be evaluated if the result is to be meaningful.

It should also be borne in mind that a property can only be assessed as useful to characterize a material, product or system if the measurement of the steady-state thermal transmission properties of the specimen and the calculation or interpretation of the thermal transmission characteristics represent the actual performance of the product or system.

The design and operation of the guarded or calibrated hot box is a complex subject. Figure 2 show typical arrangements of the test specimen and major elements of the apparatus. Figure 3 show alternative arrangements. Other arrangements, accomplishing the same purpose, may be used. The effect on the heat transfer through the specimen of the box walls in Figure 2 and of the frame in Figure 3 depends upon the wall or frame shape and material, upon the specimen thickness and resistance and such test conditions as temperature differences and air velocities. The apparatus design and construction should be made compatible with the expected types of specimen to be tested and expected testing conditions.

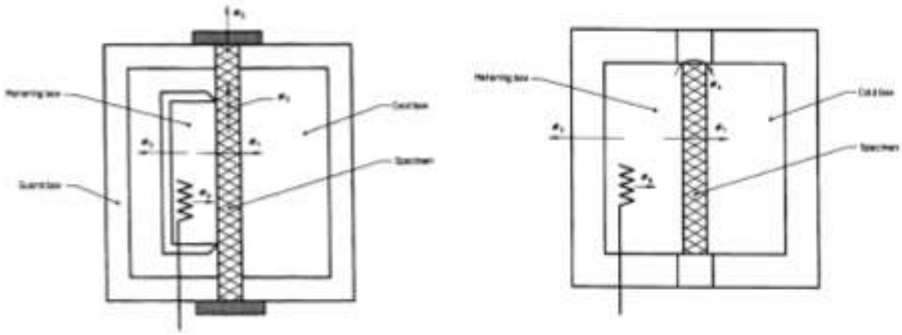


Figure 2 Typical arrangements of the test specimen (1)

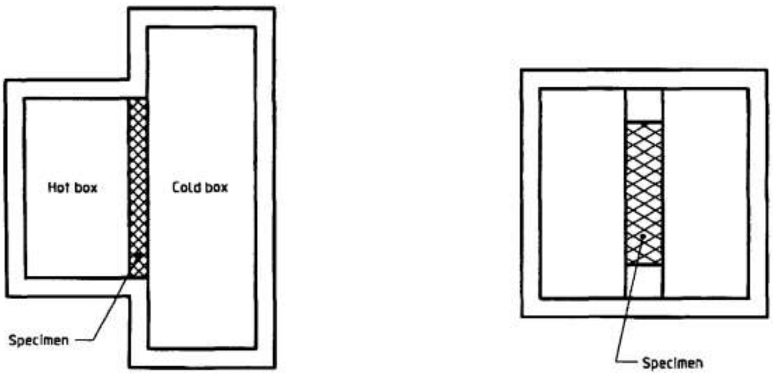


Figure 3 Typical arrangements of the test specimen (2)

3.2.1 Design requirements

The size of the apparatus shall be commensurate with the intended use, taking the following points into consideration. The metered area shall be big enough to provide a representative test area. For modular components the metered area should preferably span exactly an integral number of modules.

The ratio of metered area to perimeter of the metered area influences accuracy in both types of boxes because one-dimensional heat flow cannot be maintained at the perimeter of the metered area. These error heat flows at the perimeter of the metered area, measured as a fraction of the metered heat flow, will increase with decreasing metered area.

In general, the size of the metering box determines the minimum size of other elements of the apparatus. The depth of the metering box should not be greater than that strictly necessary to maintain desired boundary conditions (desired boundary layer thickness, etc.) and to accommodate its equipment.

3.2.2 Specimen selection and mounting

The test specimen shall be selected or constructed in such a way that it is representative. In the guarded hot box, when possible, thermal bridges should be placed symmetrically over the borderline between metering and guard area, so that half of the area of the thermal bridge is in the metering box and the other half is in the guard box.

In the calibrated hot box, the effect of thermal bridges at the specimen edges upon the flanking transmission should be considered.

The specimen shall be mounted or sealed in such a way that neither air nor moisture will gain ingress into the specimen from the edges or pass from the hot side to the cold side or vice versa.

It shall be considered whether it is necessary to seal either face of the specimen to avoid air infiltration into the specimen and whether it is necessary to control the dew point of the air on the hot side.

3.2.3 Test conditions

Test conditions shall be chosen considering end-use application, taking into account the effect of testing conditions on accuracy. Both mean test temperature and temperature differences affect test results. Mean temperatures of 10 °C to 20 °C and a difference of at least 20°C are common in building applications. Air velocity on the hot and cold sides shall be adjusted according to the purpose of the test.

3.2.4 Measurement periods

The required time to reach stability for steady-state tests depends upon such factors as thermal resistance and thermal capacity of the specimen, surface coefficients, presence of mass transfer and/or moisture redistribution within the specimen, type and performance of automatic controllers of the apparatus. Due to variation of these factors, it is impossible to give a single criterion for steady state.

3.3. Acoustic Insulation

3.3.1 Procedures

A qualitative evaluation of the acoustic behavior of the concretes will be performed by ultrasonic investigations. Ultrasonic Pulse Velocity (UPV) tests will be carried out according to the standard *EN 12504-4* (*Testing concrete – Determination of ultrasonic pulse velocity*) that specifies a method for the determination of the velocity of propagation of ultrasonic pulses in hardened concrete. This technique is considered as non destructive testing (N.D.T.) since it is used for checking the hardened concrete properties without damaging it.

The principle of the test is the following:

- an ultrasonic pulse is produced by an electro-acoustical transducer held in contact with one surface of the concrete under test;
- after traversing a known path length in the concrete, the pulse of vibration is converted into an electrical signal by a second transducer and the transit time of the pulse is measured (transit time is the time taken from an ultrasonic pulse to travel from the transmitting transducer to the receiving transducer, passing through the interposed concrete).

It is possible to make the test by placing the two transducers on opposite faces (direct transmission) or in adjacent faces (semi-direct transmission) or on the same face (indirect transmission) of the concrete specimen. In this study the direct transmission configuration will be applied.

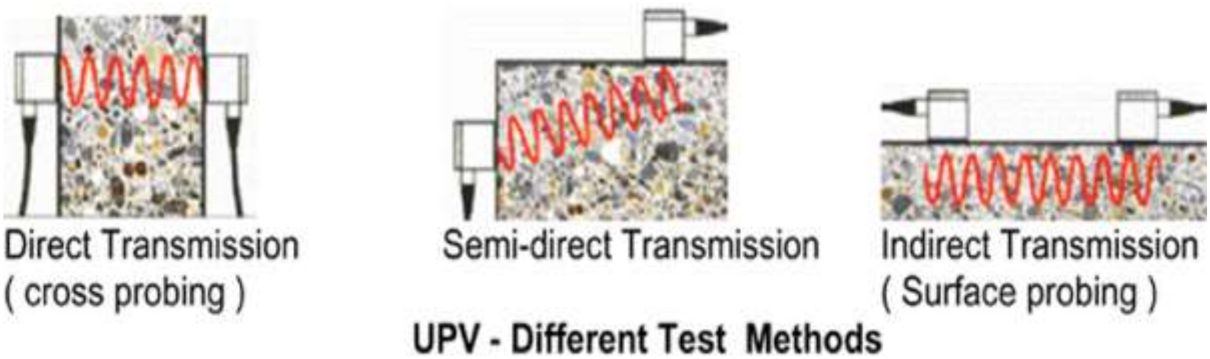


Figure 4 Transducer positioning in UPV tests.

The pulse velocity, for direct and semi-direct transmissions, will be calculated using the following formula:

$$v = l/t \qquad (1)$$

where:

- v is the pulse velocity in km/s;
- l is the path length in mm;
- t is the time taken by the pulse to transverse the length in µs.

It should be taken into consideration that there are various factors which can influence the pulse velocity measurements in a concrete, this in turn might induce eventual inaccuracies in the measurements. Among these factors can be considered the moisture content (mainly related to the curing conditions of concrete) or the presence of cracks and voids (reduction of the transit time when the ultrasonic pulse meets a concrete-air interface).

3.3.2 Samples specifications

For SUS-CON project the evaluations based on ultrasounds (determination of transit time and pulse velocity) will be performed on the following prototypes:

- panels having dimensions 0.50 x 0.50 x 0.15 m;
- blocks having dimensions 0.50 x 0.50 x 0.20 m.

Panels and blocks to be tested will be manufactured with the concretes developed in Task 4.2 of the Project and optimized for each target application. More specifically - based on the performance achieved in terms of workability, density and resistance - for blocks PU4, RX11, TR4 and PU11 mixes were selected while for panels RX4 and PU21 mixes resulted as the more suitable (for further details see also D4.4). More specifically, among the mixes above reported one will be selected for panels and another one for blocks. Finally, in addition to the characterization of SUS-CON prototypes (panels and blocks) also the performance of traditional prototypes, having similar specifications, will be carried out in order to perform a comparison of the achieved performance.

3.4. *Mechanical Test*

Consorzio TRE will perform mechanical test on prototypes and specifically flexure tests up to failure on full scale flat panels. Below is described the possible test setup referred to the actual design of prototypes.

3.4.1 Test setup

Flexure tests on flat panels will be conducted to determine the sandwich flexural stiffness, the core shear strength, and shear modulus by a Four-Point Bending scheme (Figure 5).

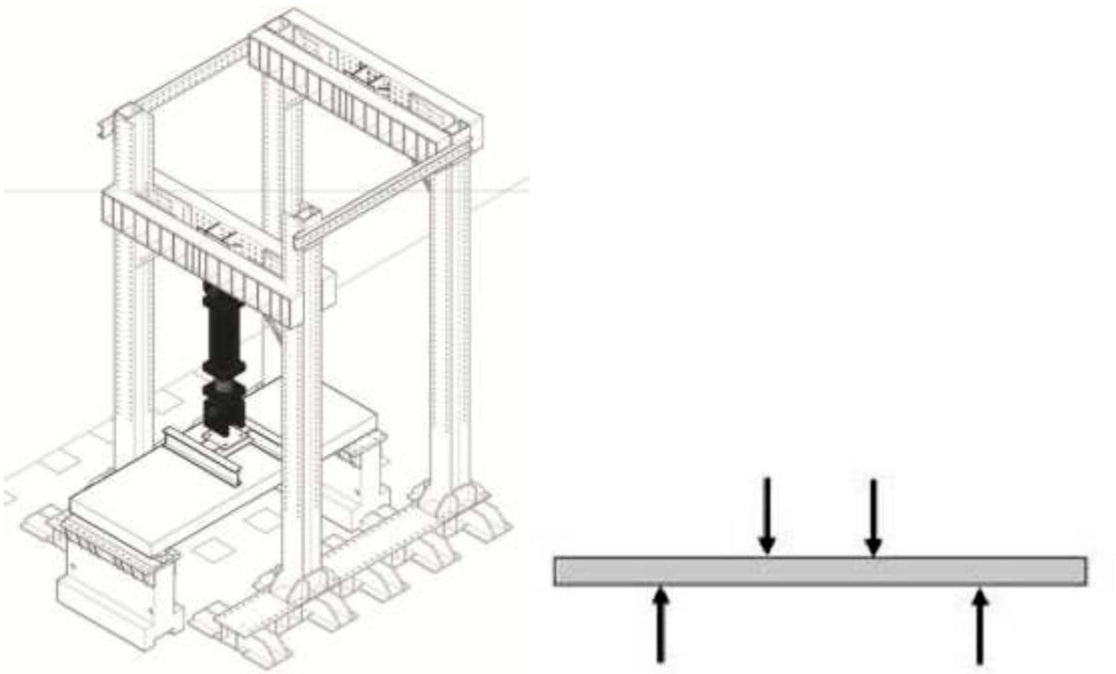


Figure 5 Loading scheme

To carry out the tests will be used a steel frame supporting the actuator and with appropriate dimensions to contain the size of the specimens to be tested.

Figure 6 Example of a test setup in the laboratories of Naples University[3]

The structure consists of two movable frames of contrast, each arranged for the anchorage of the load device (hydraulic actuator MTS, fig.7), connected by two binaries.

Figure 7 Hydraulic actuator MTS

[3] Official Laboratory Testing Materials and Structures "Adriano Galli" - Department of Structures for Engineering and Architecture, University of Naples Federico II

3.5. Thermal Bridges

3.5.1 Procedures

A qualitative detection of thermal irregularities of the concretes will be performed by thermographic investigations. Infrared (IR) method will be applied according to the standard *EN 13187* (*Thermal performance of buildings – Qualitative detection of thermal irregularities in building envelops*) for the determination of thermal irregularities of the hardened concrete. Infrared imaging is a non destructive (N.D.T.) which determines the thermal behavior of building materials is situ. Through infrared imaging thermal bridges, moisture absorbed as well as other parameters related to a building's thermal and energy behaviors can be determined.

The principle on which this test is based is described in the following. The energy emitted by a surface at a given temperature is defined by Stefan-Boltzmann's Law:

$$E = \varepsilon\sigma T^4$$

where:

- E is the energy emitted per unit of area in $W/m^{2;}$
- ε is the emissivity which depends on the material;
- σ is the Stefan-Boltzmann constant (5.67×10^{-8} W/m^2K^4);
- T is the temperature of the surface in K.

In the specific case of building components, each element if exposed to the same thermal conditions (i.e. solar radiation) will reach a specific temperature, depending of its thermal properties (specific heat and thermal conductivity).

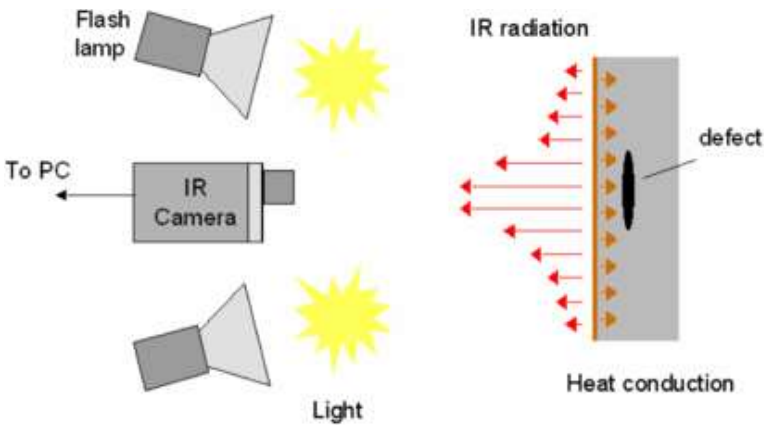


Figure 8 Apparatus for thermographic test

According to the above mentioned law each component of the building will emits an energy, depending on the reached temperature and its emissivity. Infrared thermography has indeed the aim to monitor and record these emissions by an IR detector (i.e. IR camera), operating with wavelengths 2-12 µm. The IR camera converts the emissions of the tested surface into a two-dimensional image, in which variation in emissions are displayed as a range of colors and tones (i.e. thermogram).

The operational steps of a thermographic test mainly consist in the determination of the superficial temperature distribution by an IR camera followed by the detection/evaluation of eventual anomalies (i.e. insulation defects, moisture and/or air infiltration). Irregularities in the thermal properties of the components of a building envelope result in temperature variations over the surfaces of the structure, therefore surface temperature distribution can be used to detect these anomalies. The IR thermal imaging system, with respect to other conventional instruments, has the advantage to be faster meaning that all the areas, not just the suspected ones, can be quickly scanned to determine if eventual defects are present.

3.5.2 Samples specifications

For SUS-CON project the thermographic evaluations will be directly performed on the demo site in Spain (in the facility of the partner Acciona), this will consists of two cubic structures (side 2.50 m) having:

- walls (2.50 x 2.50 x 0.15 m) made with panels;
- facades (2.50 x 2.50 x 0.20 m) made with blocks.

Panels (1.25 x 1.25 x 0.15 m) and blocks (0.5 x 0.2 x 0.2 m) will be manufactured with the concretes developed in Task 4.2 of the Project and optimized for each target application. More specifically - based on the performance achieved in terms of workability, density and resistance - for blocks PU4, RX11, TR4 and PU11 mixes were selected while for panels RX4 and PU21 mixes resulted as the more suitable (for further details see also D4.4). SUS-CON panels and blocks to be manufactured should be possibly representative of all the mixes selected (at least two for blocks and other two for panels) in order to give, once the characterization will be performed, an overall evaluation of the concretes developed within the Project.