**Project Title:**

“Green Integrated Structural Elements for Retrofitting and New Construction of Buildings”

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| Deliverable No | D 5.4. |
|----------------|--------|
| Deliverable Title | Structural Adhesive with integrated CDW |
| Work Package and Task Number | Work Package 5 - Task 5.4 |
| Participants: | ☒ 1- UBRUN ☒ 2- CID ☒ 3- LEITAT ☒ 4- NTUA ☒ 5- CETRI ☒ 6-EXERGY ☒ 7- ALCN ☒ 8- STRESS ☒ 9- UAV/R ☒ 10- ARTIA ☒ 11- NRGIA ☒ 12- COLL ☒ 13- COOLH ☒ 14- ACCIO |

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1. Project Summary

The Green INSTRUCT project aims to develop a prefabricated modular structural building block that is superior to conventional precast reinforced concrete panels by virtue of its reduced weight, improved acoustic and thermal performance and multiple functionalities. The Green INSTRUCT block consists of over 70% of CDW in weight.

The Green INSTRUCT project is going to:

(i) achieve sustainability and cost savings through CDW sourced materials and C2C,
(ii) develop efficient, robust, eco-friendly and replicable processes,
(iii) to enable novel cost efficient products and new supply chains,
(iv) develop a building block that renders refurbished or new buildings safe and energy efficient and
(v) safeguard a comfortable, healthy and productive environment.

They can be achieved by defining the structural, thermal and acoustic performance of our final product to be competitive to similar products in the market. The types and sources of CDW are carefully identified, selected and processed while the supply chain from the sources, processing, fabrication units to assembly site of the whole modular panel will be optimized.

The project is guided by a holistic view through building information modelling and optimal overall performance. This includes considering the life cycle analysis, weight, structural performance, thermal and acoustic insulation, connectivity among modular panels and other structural/non-structural components as well as the compatibility of different internal parts of each modular panel. In order to homogenize the production process, almost all individual elements are fabricated by extrusion which is a proven cost effective, reliable, scalable and high yield manufacturing technique. The concept, viability and performance of developed modular panels will be verified and demonstrated in two field trials in test cells.
2. Glossary of Terms

| Acronym | Meaning                                      |
|---------|----------------------------------------------|
| EC      | European Commission                          |
| EU      | European Union                               |
| CDW     | Construction and Demolition Waste            |
| WP      | Work Package                                 |
| PU      | Polyurethane material                        |
| ST      | Silane Terminated polymer                    |
| 2C      | Two components (resin and hardener)          |

2.1. Definitions

Words beginning with a capital letter shall have the meaning defined either herein or in the Rules or in the Grant Agreement related to the Project.

2.2. Additional Definitions

- **Project**: Project refers to the Green INSTRUCT project funded from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 723825.
- **Construction Demolition Waste**: means those materials resulting from the alteration, construction, destruction, rehabilitation, or repair of any manmade physical structure including houses, buildings, industrial or commercial facilities, and roadways.
3. Introduction

The main objectives of WP5 are to:

- Process and produce reinforcing fibers from PET, PVC, PE, wood and textile,
- Encapsulate PCMs in concrete aggregates,
- Recycle and produce a structural aluminum frame, and
- Integrate recovered CDW in structural adhesives.

In particular, the task 5.4, lead by COLLANTI CONCORDE, has to develop a structural adhesive with the as much CDW contents as possible. Several combinations have been tested in order to meet all the technical requirements and delivery a sustainable solution. These combinations aim to bond and fulfill the structurality of the glue, in terms of tensile strength. Several specific objectives should be addressed in this task:

- The introduction of CDW materials into the adhesive, to increase adhesion properties and the tensile strength of the bonding system, due to the specificity of the CDW materials used (cement powder as filler, PU foam powder and PE fibers as additives)
- Different joining systems will be evaluated to determine which is the most suitable for a new structural adhesive (PU, one and two components, ST polymer, one and two components).
- Development of sandwich structures by the combination of different materials developed during the project (PU foam panels, Al recycled, Geopolymers).

In particular, Deliverable 5.4 has focused on the description of the procedures and the results to obtain an innovative adhesive solution for GREEN INSTRUCT project:

- after the evaluation of the characteristics of the CDW materials of the project and their compatibility with the chemical properties of the adhesive.
- after the evaluation of the characteristics of the glue bonding line (viscosity, open time, VOC contents, ease of application, elastic properties, hardness).
4. Processing of bonding technology

4.1. Preliminary analysis

The main objective of Task 5.4 is to develop a structural adhesive with the high content of CDW incorporated in the matrix of the glue, more than 60% by weight. Naturally, the developed adhesive should be easy to apply, easy to be industrialized, have a competitive price and be recyclable in high extent.

Below the list of considered and tested materials

- CDW cement powder, provided by NRGIA;
- CDW PE fibers, provided by LEITAT;
- CDW powder PU foam, provided by CIDETEC.

In the frame of T5.4 COLLANTI CONCORDE investigated the chemical compatibility and, consequently, the adhesive properties and performances between the adhesive developed and the materials to be bonded.

The materials bonded are:

- The CDW PU foam panels, provided by CIDETEC;
- The CDW Aluminum frames, provided by ALCN;
- The CDW Geopolymers, provided by NTUA.

According to the timetable, the first step it was a benchmarking of the existing adhesives suitable for the GREEN INSTRUCT application. The initial research focused on a Polyurethane adhesive and a Silane Terminated adhesive, both selected according to their performances: high compatibility with additives and CDW materials, possible structural solution, low VOC contents, high versatility of bonding.

The preliminary assessment has been conducted considering glues typologies and analysis of chemical properties of each of them in order to fulfill GREEN INSTRUCT requirements and start working on glue’s characterization.

The next pictures (Figs. 1 and 2) show the typologies of chemical polymers used. These polymers have been modified in order to obtain the properties required, object of this task 5.4.
Table 1 contains a preliminary comparison between the two adhesives. Initial consideration has been done starting on glue’s mechanical properties, the PU is more rigid and strong in terms of tensile strength then ST glue, due to its higher hardness and lower elasticity. Conversely ST is more elastic and less strong in terms tensile strength. This feature is directly related to the thermal performance of the bonding because an elastic adhesive compensates also the highest thermal expansions of materials. Considering the Voc and S-Voc content, PU has a lower initial content.

**Table 1. Description of polymers**

|                | ST BASED                        | PU BASED                        |
|----------------|---------------------------------|---------------------------------|
| CHEMICAL STRUCTURE | Silane terminated based | Polyurethane based |
| VOC CONTENT     | 0.5% < x < 2.5%                | <1.5%                           |
| STRUCTURE       | Medium-elastic                  | Medium-rigid                    |
| TENSILE STRENGTH| High (>8MPa)                    | Medium (>3MPa)                  |
4.2. Experimental tests – properties of the adhesive

4.2.1 Introduction of CDW filler (cement powder)

The first test conducted was related to the incorporation of the CDW cement powder filler provided by NRGIA. Standard formulations of a PU and ST adhesives were modified and developed with the highest content of CDW cement powder filler. The filler received was originated from a demolition waste (Fig. 3).

![CDW cement powder](image3.jpg)

**Fig. 3 CDW cement powder**

The preliminary formulation of a 2C PU adhesive consists in a mixture of polyols, additives for rheological behavior, filler (CDW), defoamer and stabilizer. The formulation of a 2C ST adhesive consists in a dispersion of Silano modified polyols, rheological additives, filler (CDW), defoamer and stabilizer, as shown in Fig. 4. The ingredients were mixed and correctly dispersed until complete homogenization. Later, a vacuum operation was necessary to avoid the negative effect in terms of stability of the content of moisture in the raw materials, especially in the CDW powder.
The adhesives developed were used for a preliminary elongation tests in order to assess the Tensile Strength. Samples of hardened glues were developed with a specific mold, as required by the standard ISO 37:2011 (Fig. 5a). The standard versions of PU 2 components and ST 2 component glues were tested in parallel with the new formulations with CDW filler, for preliminary assess the behavior of the new adhesives with a dynamometric machine (Fig. 5b).

![Fig. 4](images/fig4.jpg)

**Fig. 4** (a) mixing of PU and ST adhesives (b) consistency of PU and ST adhesives (c) final mixing of PU and ST adhesives
The samples prepared were tested by a dynamometer (Fig. 6), in a single lap shear test. The machine performs a tensile load, where it is possible to measure the elongation and the stress at breaking of the sample.

This result has recorded in several graphs, sample below (Fig. 7), which it can be noted different adhesives behavior (standard formulations compared with new versions of PU and ST glues).
The preliminary results are summarized in the Table below:

**Table 2. Preliminary results of PU and ST formulations**

| PRODUCT               | ELONGATION (%) | HARDNESS (Shore A) | TENSILE STRENGTH (MPa) |
|-----------------------|----------------|--------------------|------------------------|
| PROTOPUR* L 2520/2C   | 10             | 95                 | 8.2                    |
| STANDARD              |                |                    |                        |
| PROTOPUR L 2520/2C    | 25             | 95                 | 8.5                    |
| NEW                   |                |                    |                        |
| EXTRABOND** 2C        | 65             | 45                 | 0.8                    |
| STANDARD              |                |                    |                        |
| EXTRABOND 2C NEW      | 65             | 45                 | 0.8                    |

*: Protopur is the trade name in COLLANTI for PU adhesive

**: Extrabond is the trade name in COLLANTI for ST adhesive
Due to this consideration COLLANTI conducted several tests on ST and PU glues and finally focused on PU bonding system, especially considering the high value of Tensile Strength of the PU bonded samples compared to the ST samples.

### 4.2.2 Introduction of PE fibers

After the evaluation of CDW filler use for adhesive’s formulation development, COLLANTI consider as next step, to test and introduce PE fibers in the polyurethane matrix, adjusting the maximum quantity of CDW filler as possible in a new PU 2C formulation in order to test adhesive properties. Two new formulations were made, with an important increased quantity of filler up to 62%. The new formulations have different combination of additives and stabilizers, with and without a small percentage of fibers (2% by weight).

As shown in the Fig. 8, the incorporation of the PE fibers into the polyurethane matrix was very challenging. This aspect has caused, probably, by an incompatibility between fibers and the long polyurethane chains. This aspect is reflected in the next Fig. 9, where it is possible to notice that the value of tensile strength of the sample without fibers is higher than the value of the sample with the incorporation of fibers.

![Fig. 8](image_url) (a) PE fibers (b) testing of PU adhesive sample with PE fibres (c) exposed PE fibers in the PU matrix
In the Table. 3 results obtained by PU formulations (with and without fibers) have been summarized. It is extremely clear that this new formulation, due also for the CDW cement filler usage, highlights a great increase of Tensile Strength, up to 18.9 MPa. This value is more than double then the standard PU 2 component formulation used as COLLANTI CONCORDE commercial gamma. Also, notice that the formulation with fibers, despite the non-optimal dispersion of the fibers in the PU matrix, has a value of tensile strength higher that the standard COLLANTI CONCORDE’s PU 2 components formulation.

**Table 3.** Results of tests of PU adhesive with CDW filler and fibers

| PRODUCT          | CDW Fibers | CDW Filler | ELONGATION (%) | SHORE D | TENSILE STRENGTH (MPa) |
|------------------|------------|------------|----------------|---------|------------------------|
| PROTOPUR L 2520/2C | No         | No         | 10             | 50      | 8.2                    |
| L2520/2C #1      | No         | 62%        | 1.5            | 80      | 18.9                   |
| L2520/2C #2      | 2%         | 62%        | 1.5            | 80      | 13.9                   |
4.2.3 Introduction of PU foam powder

Finally, the possibility of introducing into the PU matrix a small percentage, about 1% by weight, of CDW polyurethane foam powder was investigated.

PU powder samples formulation was obtained from a polyurethane solid foam Fig. 10. The test aimed to verify the possibility of a perfect incorporation of a two similar and compatible material like polyurethane foam powder in a PU adhesive matrix and evaluate the properties of this experimental introduction, checking if this incorporation provides the increase of the structural properties of the developing adhesive.

![PU CDW powder](image1.png)  ![PU CDW panels](image2.png)

*Fig. 10* (a) PU CDW powder and (b) PU CDW panels

A batch of PU 2 components adhesive was prepared and separated in two parts with a different use of PU foam (one with 0.5% and the other without). Those two different combinations were both catalyzed, the samples made in the mold and tested in the dynamometric machine (Fig. 11) after curing.
In this phase, the effect of a Pre-heating treatment on CDW materials into the finale PU adhesive matrix was examined: all the CDW materials were heated for 1h with fixed temperature of 80°C, in order to reduce the content of moisture into the raw materials. The molecules of water incorporated into the polyurethane matrix have a competitive and preferential reaction with the molecules of isocyanates of the catalyst, and the result is the quick creation of carbon dioxide foam, and this effect is clearly visible in the Fig. 11b, where on the right side there is the hardened adhesive sample without pre-heat treatment, and on the left side there is the sample with this treatment.

This effect is also naturally reflected on the results of the measurement of tensile strength, as visible in the next Graph (Fig. 12):

Characteristics of the new developed polyurethane 2 components adhesive were summarize in the table n°4. The name of the new adhesive is PROTOPUR GI/2C.

The final Tensile strength value obtained during the single lap shear test with the different formulations developed with the highest value of CDW content, as filler, fibers or PU powder, are very different, depending on the CDW incorporated in the PU matrix: if the incorporation of cement filler increases strongly the internal cohesion of the polyurethane cross-linkage, probably the incorporation of fibers and PU powder doesn't have the same
effect, both for incompatibility with the fibers and the PU matrix, both for the difficult to incorporate lightly powder in the same PU matrix.

Table 4. Final results of developed adhesive

| PRODUCT      | CDW PU | CDW Filler | Pre-heating step | ELONGATION (%) | SHORE D | TENSILE STRENGTH (MPa) |
|--------------|--------|------------|------------------|----------------|---------|------------------------|
| PROTOPUR L2520/2C | No     | No         | Yes              | 10             | 50      | 8.2                    |
| L2520/2C #3  | No     | 62%        | Yes              | 1.8            | 85      | 23.3                   |
| L2520/2C #4  | No     | 62%        | No               | 1.8            | 60      | 19.7                   |
| L2520/2C #5  | 0.5%   | 62%        | Yes              | 2.1            | 85      | 12.8                   |
| L2520/2C #6  | 0.5%   | 62%        | No               | 2.2            | 60      | 11.1                   |

It follows that for testing the bonding with the CDW materials developed during the project (Aluminum frames, PU foam, Geopolymers) it will be produced and used the best adhesive’s solution, the one filled only with the 62% of cement powder as a filler.

4.3. Experimental tests – Bonding operations

The experimental test phase aims to tests the behavior of adhesive bonding properties, different bonding tests were conducted using adhesive developed (Protopur Gi/2C) with different materials, and then analyzed: first, COLLANTI CONCORDE tested adhesive with market standard materials, such as Aluminum and PS, then tested adhesive with the materials developed during the project with CDW materials, like PU foam (from CIDETEC) and Aluminum frames (from ALCN).

In the first step, Protopur Gi/2C was prepared mixing all the raw materials necessary and the glue was catalyzed with the specific hardener (Methylene diphenyl-methane di-isocyanates based, called CTZ GI17), and correctly mixed manually for a few minutes. The mixed glue is easily applied with a standard spatula, on an Aluminum surface, pre-treated with Acetone for avoiding detaching substances or dust on the Aluminum surface. After the application of the glue, the second bonding element, PS in this case, was put on
and the “sandwich” is left on rest, until the complete hardening of the adhesive’s mass. The final result is visible in the Fig. 13: the “sandwich” is perfectly bonded.

![Fig. 13](image)

Fig. 13 (a) Preparation (b) mixing (c) application and (d) final bonding of the adhesive

Another example of bonding pieces is visible in the next pictures (Fig. 14), once again obtained bonding Al frame and PS. The result is another perfect bonded piece, no relevant detaching or compatibility problems were showed.

![Fig. 14](image)

Fig. 14 Example of bonding operation with (a) Al frame and (b) PS

After these preliminary tests of adhesion, the GREEN INSTRUCT project involves the use of the new adhesive for bonding the new materials derivated from CDW: PU foams, Aluminum frames and Geopolymer surfaces. The first test with the project’s materials developed was the bonding of a sample of Geopolymers developed by NTUA with Protopur GI/2C (Fig. 15): as showed in the picture below, the adhesive has a perfect adhesion and compatibility with this material.
This condition to us means that the adhesive is suitable for this kind of bonding application as well as compatible with this kind of materials. It means also that it's sufficiently strong to have a complete substrate failure without any cohesive failure.

The next bonding operation was made with the other developed project's materials: some samples of PU foam with two different physical properties (soft and hard) have been prepared by CIDETEC (Fig. 16a). Some samples of recycled Aluminum pieces have been prepared by ALCN (Fig. 16b).

PU foam was cut and prepared for dynamometric bonding tests, as shown in the next pictures. Different PU foams were glued each other and also with the Al surface, and samples are made for testing the quality of bonding between adhesive and materials, and the Tensile Strength and the elongation of this “sandwich”.

Fig. 15 (a) Bonding of Geopolymer with PS using Protopur GI/2C (b) remaining PS after forced separation

Fig. 16 (a) CDW PU foam and (b) CDW Al surface
As we can see in the next pictures (Fig. 17), the dynamometric tests cause the complete PU foam breakage.

![Dynamometric test with PU foam](image1)

![Fracture surface of PU foam](image2)

**Fig. 17** (a) Dynamometric test with PU foam (b) fracture surface of PU foam with Protopur GI/2C

We conducted the same tests also for Aluminum and results was the same: the dynamometric tractions cause the complete breaking on the foam side, both soft and rigid samples (Fig. 18).

![Dynamometric tests with Al surface](image3)

![Rigid PU foam](image4)

![Soft PU foam](image5)

**Fig. 18** Dynamometric tests with Al surface and (a) rigid PU foam and (b) soft PU foam
In summary, the adhesive solution developed by COLLANTI CONCORDE for the EU project GREEN INSTRUCT named Protopur GI/2C, is suitable for bonding all the different CDW materials developed in the same project, like Aluminum frames, PU foams (soft and hard), and Geopolymers. In all the bonded pieces made with this materials, this PU 2 components glue have a perfect adhesion and compatibility, without adhesive failures.

5. Green Instruct adhesive results

5.1. Characteristics of the developed adhesive

The main features of the new adhesive developed for the GREEN INSTRUCT project are summarized in the following table (Tab n°5):

| Technical Features PROTOPUR GI/2C | in comparison with standard Protopur L2520/2C |
|----------------------------------|-----------------------------------------------|
|                                   | L2520/2C          | GI/2C            |
| Viscosity                        | 10000cps         | 100000cps        |
| Mixing ratio with CTZ GI17       | 4 to 1           | 4 to 1           |
| Pot Life of the mixture          | 40 minutes       | 30 minutes       |
| Minimum Pressing Time            | 4 hours          | 3 hours          |
| Tensile Strength (single lap shear test) | 8.2 MPa   | 23.3 MPa        |
| Shore D                          | 50               | 85               |
| Final Hardening Time (2mm thickness) | 24h          | 24h               |
| VOC                              | < 0.1            | < 0.1             |

(See Annex 1 for Technical Data Sheet of Protopur GI/2C)
6. Conclusions

The aim of this task was to develop a new structural adhesive with the highest content of Construction Demolition Waste as possible. This CDW aggregates were sourced by NRGIA and LEITAT.

Task 5.4 was performed according to these steps:

1. feasibility study, influence of the inorganic filler based on structure-properties relationship
2. preliminary test done by a drop-in
3. development of the adhesive
4. validation of the adhesive sample, chemical-, physical- and mechanical properties

Task 5.4 comprises the following stages:

➢ The introduction of the CDW powder treated by NRGIA in a polyurethane 2 components system. A great amount of this filler was premixed in a polyurethane polyol, and the formulation was finished with rheological additives. Many batches with different growing content of filler were prepared and checked. The best result in terms of workability, stability and physical properties (viscosity, pot life, tensile strength) was obtained with a content of 62% by weight of CDW powder filler. By adding more than that percentage, a loss on wetting properties and adhesion was observed. This adhesive was characterized, evaluating shore, tensile strength, elongation, pot life and stability.

➢ The introduction of PE fibers (about 2% by weight), treated by LEITAT, in the previous adhesive. The interaction between fibers and polyurethane matrix could permit to obtain an increase in terms of tensile strength of the adhesive. Unfortunately those fibers show a great toughness, the interaction between the PU matrix and the fibers was not so as good as expected, and the final result was compromised. Another kind of pre-treated fibers, with a plasma treatment, will be tested during the next months.

➢ The introduction of a small part (about 0.5% by weight) of PU foam powder cause a decrease in the value of tensile strength, due probably to the difficult to mix this soft foam in to the Polyurethane adhesive matrix.
The results of this task are based upon material tested and upon Protopur GI formulations and modifications. Anyhow, the comparison of figures from test results shows as the target, i.e. a two-component polyurethane adhesive in the context of the Green Instruct project, has been met.

The outcomes of Task 5.4 can be summarized as following:

- A new formulation was obtained which includes a large percentage of CDW’s (62% by weight of cement powder). PE fibers and PU foam powder were tested, but without an acceptable result.
- The new formulation was characterized with excellent result in terms of structurability (Tensile Strength > 20MPa); samples were made for testing the properties of Tensile Strength, Shore and elongation. It was also tested bonding Geopolymer, Aluminum and Extruded PU foam (soft and rigid). The results obtained in terms of adhesion and Tensile Strength are excellent in comparison with a standard polyurethane 2 component product.
7. Acknowledgment

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Disclaimer

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8. Annex 1
PROTOPUR GI/2C

Two-component polyurethane adhesive for bonding various materials such as: gypsum plasterboards, cement-bonded wood fibre blocks, galvanised sheet, steel, aluminium, rockwool, expanded polystyrene, polyurethane foam, ceramic, PVC sheets. This adhesive was developed with an high content of CDW (Construction Demolition waste) fillers, in reference with the EU project Green Instruct (www.greeninstruct.eu).

CHARACTERISTICS

Sales specification:
Viscosity at 20°C (UNI EN 12092) 100.000 ± 15.000 mPa

Other technical characteristics *:
Base Polymers CDW and additives
Colour beige
Density at 20°C 1.55 ± 0.1 g/cm³
Open time of the glue mix (20°C, 55% r.h.) approx. 30 min
Pressing time of the glue mix (20°C, 55% r.h.) 3 hours
Processing time after bonding (20°C, 55% r.h.) 10 - 12 hours
Final curing time 3 - 4 days
Room and material temperatures from +10°C to +30°C
Adhesive quantity from 200 g/m² up to 600 g/m²
Suggested pressure 3 - 5 kg/cm²
Applicator By dosing machines or by hand
Cleaning Ketones
Storage in dry and cool room, in the original sealed packaging
Shelf life 6 months from the day of production
Packaging Buckets, drums, tanks

*no sales specifications
# CATALIZZATORE C17 GI17

## CHARACTERISTICS

| Specification                  | Value            |
|--------------------------------|------------------|
| Viscosity at 20°C (UNI EN 12092) | 200 ± 40 mPa.s  |

### Other technical characteristics *

| Characteristic   | Details                                      |
|------------------|----------------------------------------------|
| Base             | Methylene diphenylmethane diisocyanates      |
| Colour           | Brown                                        |
| Density at 20°C  | 1.2 ± 0.1 g/cm³                               |
| Mixing ratio     | 1 part by weight on 4 parts of PROTOPUR GI 12C |
| Shelf life       | 12 months                                    |
| Packaging        | Jerrycans, buckets                           |

*no sales specifications*

## RECOMMENDATIONS

The materials to be bonded must be free of grease, oil or oxide, that might impair theadhesion. Both components must be carefully mixed together. Apply the glue mixture to the materials then press them together. Preliminary trials are recommended to check for the adhesion on the materials to be bonded and of the final performance of the glue. Lower room and application temperatures may cause longer times. Temperatures below +5°C must be avoided. Keep containers tightly closed.

For all matters not covered in this Technical Sheet, refer to our General Sales Conditions and to the advice of our Technical Sales Dept.

COLLANTI CONCORDE acts under the ISO 9001 system. Materials and application conditions affect the final performance of our products. Preliminary trials are therefore recommended.

Issuing date: June 2016.

Material Safety Data Sheet available.

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