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A European Project for Safer and Energy Efficient Buildings: Pro-GET-onE (Proactive Synergy of inteGrated Efficient Technologies on Buildings' Envelopes)

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Abstract: The paper describes the progress of the four-year European project Pro-GET-onE currently under implementation. This research and innovation project is based on the assumption that greater efficiency, attractiveness, and marketable renovation can only be achieved through an integrated set of technologies where all the different requirements (energy, structural, functional) are optimally managed. Thus, the project focuses on the unprecedented integration of different technologies to achieve a multi-benefit approach that is provided by a closer integration between energy and non-energy related benefits. The project aims to combine different pre-fabricated elements in a unified and integrated system resulting in a higher performance in terms of energy requirements, structural safety, and social sustainability. The project attempts to achieve this goal through the introduction of innovative solutions for building envelopes to optimally combine the climatic, structural, and functional aspects through a significant architectural transformation and a substantial increase of the real estate value of the buildings. This augmented value obtained through the application of the inteGrated Efficient Technologies (GETs) is extremely important when considering the necessity of creating an innovative and attractive market in the energy renovation of existing buildings towards the target of nearly zero energy buildings (nZEBs).

Keywords: building envelope; energy efficiency; seismic improvement; sustainability

1. Introduction and State of the Art

The research project Pro-GET-onE is based on the integration of different technologies to achieve a multi-benefit approach through the closer integration between energy and non-energy related benefits, promoting a holistic vision based on the integration of different technologies where numerous requirements (energy, structural, functional) are managed as a whole. Thus, by implementing a same holistic and integrated system based on pre-assembled components, the research project aimed to achieve the highest performances in terms of:

1. energy requirements—by adding (or substituting the existing with) new prefab and plug and play high energy performing envelopes and HVAC (Heating, Ventilation, Air Conditioning) systems;
2. safety—using appropriate external structures to increase the overall structural capacity of the building while supporting the new envelope consisting of timber based components for opaque parts/surfaces, and aluminum, glass, PV photovoltaic, solar panels;

3. social and economic sustainability—increasing the real estate value of the buildings and the desirability of retrofit options by providing tailored and customized solutions for users, owners and house managers, increasing safeness and minimizing disturbance to inhabitants.

The goal of this research project was to provide the market with an innovative, yet readily implementable system for the building envelope to be applied to an energy, structural, and user-oriented retrofit that would significantly increase the commercial value and the life cycle of buildings, involve the users in attractive and visible solutions and, ultimately, reduce the costs of energy retrofit options in the whole building life cycle. This goal will be attained through the application of solutions for the building envelopes, as well as through optimum climatic-structural-functional management, grounded on the substantial increase of the real estate value of the buildings through significant energy and architectural transformation. This incremented value will be obtained through the development and application of inteGrated Efficient Technologies (GETs) with the strategic aim of creating a new and attractive market in the deep renovation of existing buildings towards the target of nearly zero energy buildings nZEBs [1].

By coupling and combining these technologies, Pro-GET-onE aims to provide existing buildings with poor structural performance with improved, safer seismic performance to get as close as possible to the levels of the European standard EN 1998, Eurocode 8 [2].

Housing in the European Union (EU) represents a huge part of the building stock. EU dwelling stocks account for about 200 million units, representing around 27% of energy consumption in the EU: the potential reduction in CO_2 emissions that energy efficient housing would provide cannot be underestimated. Three quarters of the buildings standing today including the residential stock are expected to remain in use in 2050. So far, only 1.2% of the EU's existing buildings are renovated every year [3,4]. The EU's energy efficiency challenge in buildings mainly concerns the energy efficient refurbishment and investments in its existing building stock. However, there is a clear investment gap in this sector with regards to the private housing market.

The cost-benefit assessments of retrofit actions in this sector have shown excessive payback times (payback times are up to 35–45 years). Furthermore, high investments are required up-front and are generally characterized by a high degree of risk with a potential limited return on investments.

In the Mediterranean and seismic areas of the EU, this gap is even exacerbated, being associated with a strong and generalized lack of confidence by the final users and owners and by weaker market conditions. In fact, the harder economic crisis that these areas are experiencing and the lack of confidence in the perceived sense of safeness in the majority of existing buildings are both major barriers when approaching the subject on building retrofit.

Information from the SHARE Project [5] indicates that Italy, Greece, Romania, and the Mediterranean countries of the European Union as the areas with the highest probability of an earthquake. In these areas, recent seismic events have shown how relevant the issue of seismic vulnerability for existing buildings of reinforced concrete is, given that many of these were designed without any reference to anti-seismic criteria. The evaluation of the vulnerability of the existing buildings and the subsequent assessment of the potential benefit provided by solutions and actions for seismic improvement is a much more complex topic than the design of new earthquake-resistant buildings.

Seismic improvement solutions for existing reinforced concrete buildings can be distinguished according to the number of resistant elements involved and the strategy of the intervention adopted. Local interventions that strengthen the structural elements (beams, columns), reinforce the seismic joints, and secure the vulnerable elements are commonly used. These interventions can increase stiffness, resistance, and eventually ductility at the expense of a significant invasiveness for the users of the building.

Pro-GET-onE proposes a technique that until now has not been commonly used and can be configured as an exoskeleton connected to the reinforced concrete frame of the existing buildings. This new structure can collaborate in order to resist the horizontal seismic actions. Outstanding projects that have adopted this idea are, for example, the Magneti Marelli factory offices and warehouse buildings in Crevalcore (Italy) by Teleios Srl [6,7]. In the office building, the external structure was composed of steel frames connected to the existing reinforced concrete building where the vertical elements had been released from horizontal loads, being completely assigned to the new structure. In the warehouse of the same factory complex, the steel frames were instead inserted inside the building, directly connected to the reinforced concrete portals. Both the interventions ensured full resistance to a designed earthquake according to the current Italian regulation. However, in the described cases, the exoskeleton does not provide integrated solutions for energy improvement and possible volumetric expansion, as in the case of this research project. Another case with a similar approach, and similarly limited to the structural aspect, was the seismic reinforcement of the rural and surveying engineering department of A.U.TH., Thessaloniki, Greece [8]. This project regarded the construction of a steel exoskeleton on the entire perimeter of the existing building, thus providing structural strengthening.

Regarding energy retrofit, several studies have been already carried out to overcome the barriers of high costs and time through technological solutions using prefab systems like TES FAÇADE [9], More Connect [10], and EU Prefabricated Systems for Low Energy Renovation. Most of these solutions are generally founded on the load bearing capacity of the existing buildings, conditions that are rarely applicable in the highly seismic areas of the Mediterranean countries. Thus, in the Mediterranean and seismic areas of the EU, it has become imperative to couple energy retrofits with the development of tools to increase confidence in safeness, and to make it clear that higher initial investments of retrofit are more interesting in the long-term than lower investments with higher paybacks.

2. Multi-Benefit Solutions

As briefly discussed, renovation in buildings implies the solution of issues beyond the energetic sphere (namely structural and seismic safety, fire safety and functional, new technological networks as well as spatial and aesthetical amenities). Undeniable costs and long payback time of renovations led us to consider that an acceptable payback time for energy retrofitting was very difficult to achieve without considering the multiple benefits in economic, social, and environmental terms. In this frame, Pro-GET-onE focuses on the willingness to pay rather than the mere cost reduction. In fact, the core element of every redevelopment is the increase in value for the client (investor, building owner, and tenant), since focusing solely on the optimization of energy efficiency may result in failing to meet the overall requirements.

2.1. Structural Requirements

Regarding the structural response under seismic loading, simulations using FEM software (EN 1998) performed for different residential buildings have shown an overall reduction of horizontal displacements and internal forces of the retrofitted structures. From the perspective of maximum compatibility and a minimum invasiveness, the overarching goal of the strategy adopted was to provide an intervention that increased the capacity of the building as a whole and only secondarily acted locally on existing vulnerabilities, minimizing and/or avoiding interventions that are not cost-effective and very invasive when applied extensively. External metal bracings like exoskeletons are a suitable solution to increase the capacity of existing structures when subjected to horizontal actions by increasing the rigidity, and consequently reducing the displacements (Figure 1).

More in-depth analyses were carried out. One of the virtual cases is reported in this paragraph. Following the Italian code and guidelines NTC 2008 (which refers to the Eurocode 8), modal analysis with response spectrum (or linear dynamic) was performed. In this case, the equilibrium was treated dynamically, and the seismic action modeled directly through the acceleration project spectra obtained from the seismic parameters related to a seismic zone selected by the authors (Table 1). The results shown below correspond to a seismic action determined with the following data:

Table 1. Seismic parameters of Bologna.

Bologna, Emilia Romagna—Seismic Zone III (NTC 2008)
SLV (SD)—P_{VR} = 10%; T_R = 475 years; V_R = 50 years
• a_g/g = 0.166 • F_0 = 2.398 • T_C = 0.310

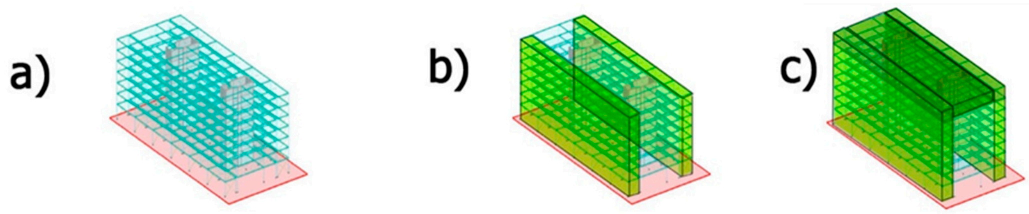


Figure 1. Model of the existing (**a**) and the new structures (**b**)—GET structure; (**c**)—GET structures connected on top—portal. This figure shows, as an example, the contribution of GETs on an existing reinforced concrete structure with columns and shear walls. The new structure (**b**)—in this example, steel columns and beams, steel stiffeners and XLAM plates when connected to the nodes of the existing building resulted in a reduction of displacements and internal forces in the existing structure (**a**). Further improvements resulted when the additional structures on each façade were connected on the top of the building (**c**).

The selected parameters allowed the evaluation of the seismic structural efficiency of the different design solutions of the GET system. As a direct consequence of earthquakes, the absolute displacements of the structure were used. As established by the code, the structure was analyzed with combined actions (SLV and SLD as indicated by the NTC 2008), with the displacements reported in both cases. Only the results of the SLV combination (coincident with the significant damage limit state for Eurocode 8) are shown since they were more severe. As part of the procedures for the analysis of structures, the fundamental period of vibration is an important feature in the evaluation of the stresses caused by the seismic action. The variations of the period depend on the mass and stiffness of the structures. The application of the steel external structure connected to the existing reinforced concrete building increases the rigidity of the structure k with a minimum mass increase, resulting in a decrease in the structure's period. In linear analysis methods, the identification of the period leads the estimation of the horizontal forces of the project. In general, it connects the capacity to seismic requirement, in order to determine the expected performance and therefore the safety design. Most common types of reinforced concrete construction were conceived and built largely between the 60s and the 90s when no clear characterization of the seismic territory had yet to be defined and horizontal earthquake actions were not considered. They were designed for only static loads or according to obsolete/poor seismic design criteria; thus, they resulted in small elemental sections and irregular rigidity distribution. To highlight the effectiveness of Pro-GET-onE, reinforced concrete buildings that had a geometric irregularity in the plan, with predominantly longitudinal development, were considered (Figure 2). Smaller section dimensions and different mechanical properties of the materials result in less resistance, leading to longer periods and displacements with a wide margin of improvement (Table 2).

The additional structure provided by the project consists of steel frame (two columns and a beam) for each floor, with bracings in the transversal direction, connected to the existing reinforced concrete frame at the column-beam joints. These frames are also connected in the longitudinal direction to create a space frame together with the existing one.

The first design solution provides a continuous addition on both longitudinal facades (Figure 3a) and therefore increases the depth of the building on the smaller side to give it a more regular geometry in plan and an increase in stiffness to cause a decrease in displacements and profile stresses.

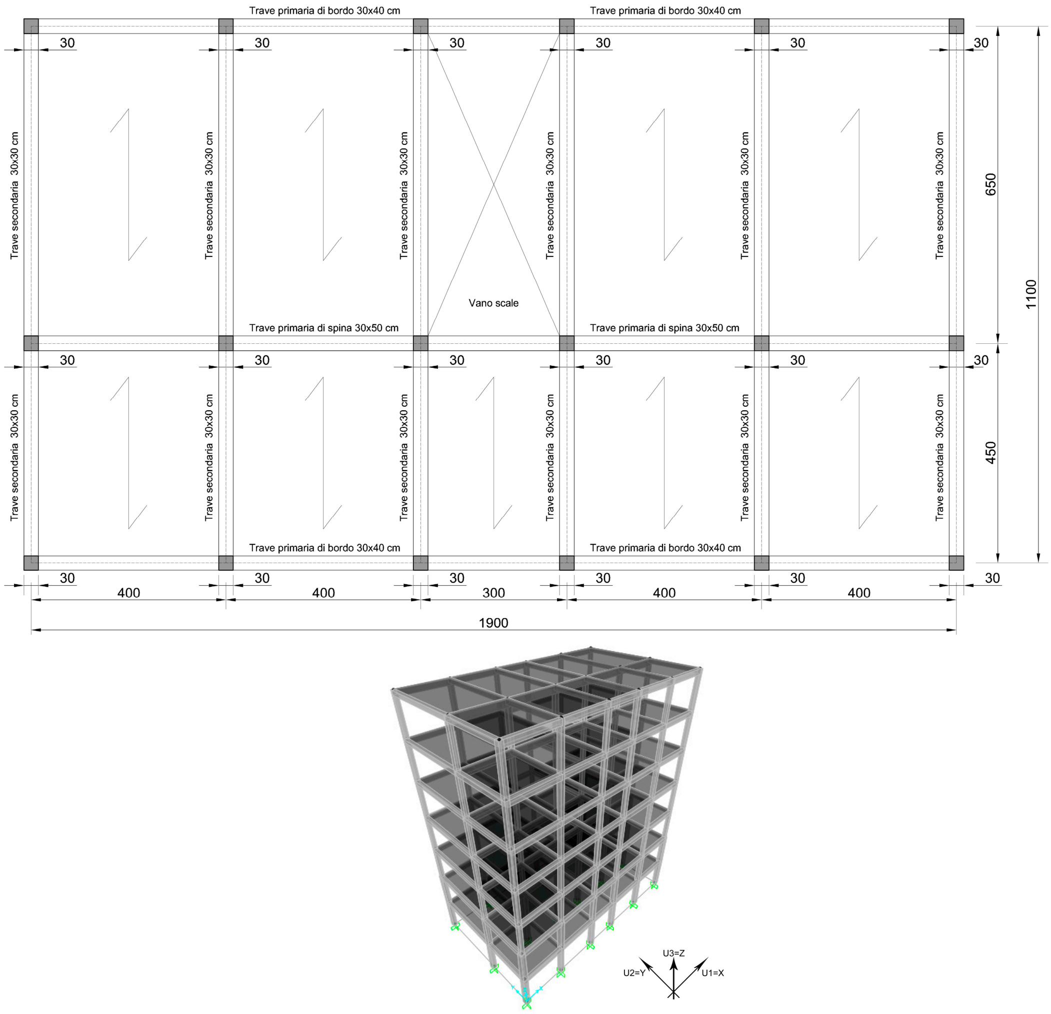
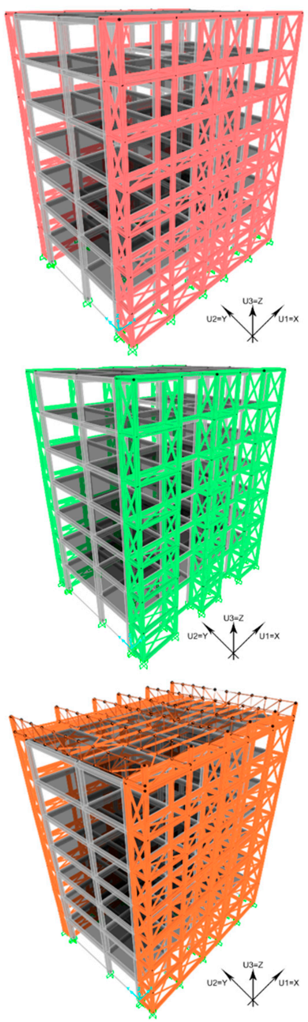


Figure 2. Plan and finite element model of the virtual case study, below there are also the main analysis results.

Table 2. Maximum displacements and periods of the initial state structure.

Maximum Displacements			Structural Periods	
Node	**U1 (m)**	**U2 (m)**	**Vibration Mode**	**T—Period**
127	0.1148	0.1618	1	2.761
139	0.1108	0.1617	**2**	2.197
			3	1.818
			4	0.896

The second solution is instead an alternate addition on the same facades (Figure 3b). This attempt provides a reduction in the amount of steel used and therefore of material costs. The alternation of exploitable spaces allows an increase in the presence of bracing frames, resulting in a substantial transversal displacement reduction. The third design solution provides an improved connection between the two lateral frames made by trusses (Figure 3c).



SLV (SD)	U2 (m)	-Δ- U2 (%)	U1 (m)	-Δ- U1 (%)
I.S.	0.162	-	0.115	-
-Δ- min.	0.099	38.75	0.080	30.75
...	...	...	...	...
-Δ- MAX.	0.052	68.05	0.056	51.22

(a)	T—Period	-Δ- T (%)
I.S.	2.761	-
-Δ- min.	1.499	45.71
...	...	...
-Δ- MAX	1.144	58.57

SLV (SD)	U2 (m)	-Δ- U2 (%)	U1 (m)	-Δ- U1 (%)
I.S.	0.162	-	0.115	-
-Δ- min.	0.096	40.67	0.082	28.57
...	...	...	...	...
-Δ- MAX.	0.056	65.64	0.062	45.82

(b)	T—Period	-Δ- T (%)
I.S.	2.761	-
-Δ- min.	1.440	47.85
...	...	...
-Δ- MAX	1.182	57.19

SLV (SD)	U2 (m)	-Δ- U2 (%)	U1 (m)	-Δ- U1 (%)
I.S.	0.162	-	0.115	-
-Δ- min.	0.099	38.75	0.080	30.75
...	...	...	...	...
-Δ- MAX.	0.052	68.05	0.056	51.22

(c)	T—Period	-Δ- T (%)
I.S.	2.761	-
-Δ- min.	1.486	46.18
...	...	...
-Δ- MAX	1.149	58.39

Figure 3. Finite element models of the three design solutions (**a**–**c**) and the related analysis results. SLV, load combination of "*stato limite di salvaguardia della vita*" (NTC 2008) equivalent to *significant damage* (SD, Eurocode 8); I.S., initial state; -Δ-, difference; T, period of vibration.

The range of results is determined by changes in the new structure as shown in Table 3 below.

Table 3. Variation and consequences obtained from FEM models.

Profiles used in the new structure	HEA 240 HEA 300	↓	↓	δ max	↓	T_1
Depth of the addition	1.5 m 2.5 m	↓	↓	δ max	↑	T_1
Connection constraint between the two structures	Hinge joints Rigid joints	↓	↓	δ max	=	T_1

In each of the designed solutions, these variations have the same effects. The increase in the size of the profile used clearly results in an improvement as it increases the overall structure's rigidity. The depth of the exoskeleton brings out conflicting effects: on the one hand, wider depths produce minor displacements as the resulting building (given by the existing and the added volumes) is more rigid; on the other hand, the same increase in depth comes across with a slightly worse period of the structure due to an increase in floor masses despite minor stiffness improvements.

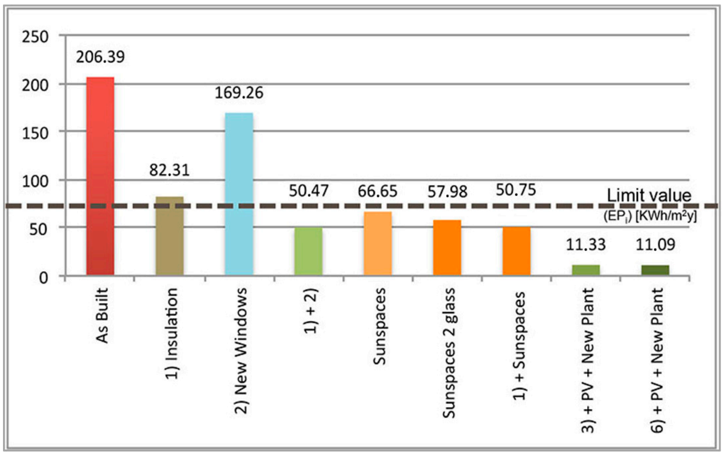
The GET system introduces a metal structure with efficient stiffness; furthermore, the GET is applied externally to the existing building with a beneficial effect in terms of construction site management given that it does not require the performance of special operations inside the existing building. The installation is less complicated with respect to the usual insertion of new reinforced concrete structures within the existing building. Moreover, with respect to this insertion, the GET structure implies a significant reduction in terms of cost for the new foundations.

Regarding the connections, the use of rigid joints results in a reduction in both displacement and period. However, it should be highlighted that this connection is not easily implemented in the construction practice. This is especially true in the case of a connection between an existing reinforced concrete structure and a new steel frame. The element of great importance for the system is the connection linking the existing structure in reinforced concrete and the new metal structure "GET". To create an effective collaboration for horizontal actions while avoiding burdening the existing structure with vertical loads, this joint is assumed as a vertically sliding joint that allows only vertical movements.

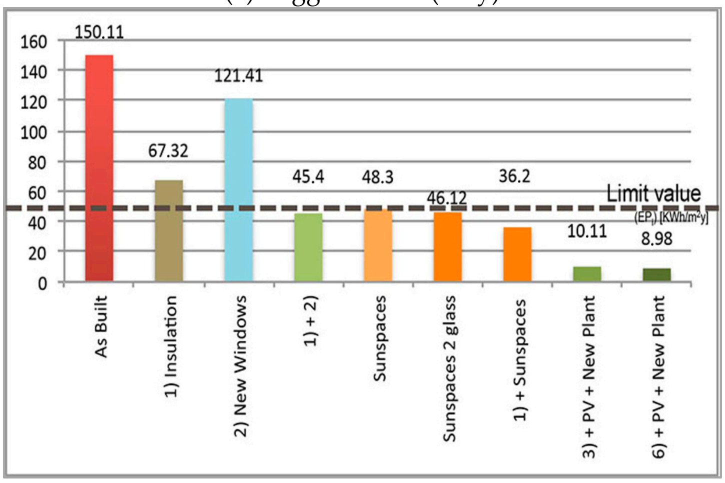
2.2. Energy Requirements

The GET structure will be combined with energy and space requirements. To this aim, energy simulations performed have demonstrated that enclosing the structure with solar spaces that can be opened in summer may provide an energy reduction of up to the 75% in the cold winter season while reducing solar gains and increasing natural ventilation rates, thus achieving about 35% energy consumption. Simulations have been performed from northern climates to the Mediterranean area reaching nZEB performances with traditional thermal insulation coating combined with controlled mechanical ventilation (VMC). Many references in the literature have also confirmed this potential energy reduction [11]. Specific calculations have been performed for the three cases of the research project by using a monthly-based method according to the EN 13,790 standards (Figure 4).

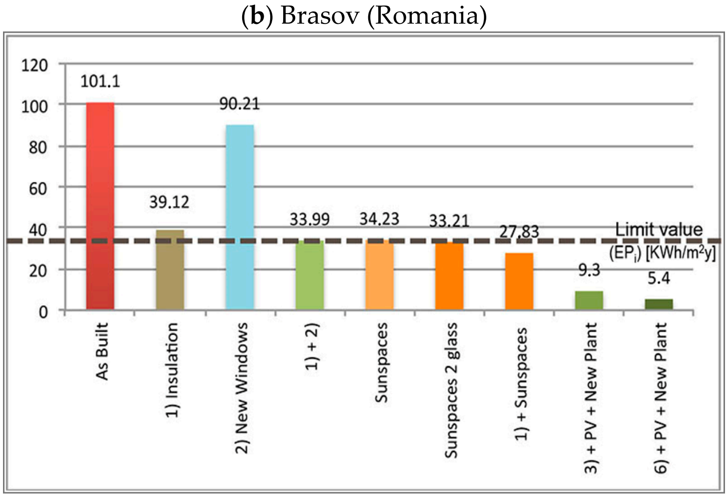
Concerning technical HVAC plants, the GET system can be coupled with new network lines (thermal fluids, electricity, etc.) with the predisposition for future systems (i.e., water drainage pipes, telecommunication lines) to be integrated in the external structure for a "plug-and-play" connection with internal devices. External allocation of all main plant system (EHP, PV system, hydraulic pipes, electric lines) will allow for simple plant maintenance and/or substitution. As a whole, GET can be equipped with several installation plants. The structure may also be used as support for the telecoms infrastructure such as to ensure easy access to superfast broadband services as required by new EU directives for new and renovated buildings [12]. Thus, Pro-GET-onE proposes the highest transformation of an existing building shell with external strengthening structures that generate energy efficient buffer zones (by reducing radiation in summer, providing solar heating in winter, and hosting flexible/adaptable plug-and-play installations), and increase the flat volume (with balconies, loggias, sunspaces, and extra rooms, according to the users' needs or expectations). See section of the GET system in Figure 5. These solutions have been designed and analyzed in a large set of existing buildings [11].



(**a**) Reggio Emilia (Italy)



(**b**) Brasov (Romania)



(**c**) Peristeri (Greece)

Figure 4. Simulations in three of the case studies show how combining the enclosure of volumes with insulation of existing envelopes will save up to 75% of the energy consumption.

Figure 5. Exoskeleton providing existing building (5) with: strengthening by GET structure (2), energy saving and plant distribution (1, 4, 6) increased comfort and living areas for residents, and additional new units (3).

Fotopoulou et al. [13] investigated an individual residential unit in a set of various hypotheses for targeted energy retrofitting interventions with different options both individually and in combination. The study was executed for three different climatic zones (Athens, Riga, Bologna) and showed that energy savings were larger during the winter period in southern climatic conditions while northern countries showed a larger energy saving during summer. Undoubtedly, in all three different climatic conditions, a zero energy building with the extension on the façade and with a standard retrofit seems to be an achievable goal.

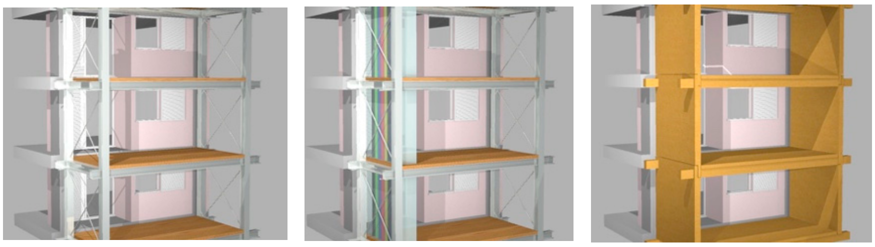
Simulations of different scenarios of the additions on the existing building resulted in corresponding diverse energy performances, from the very low grade of performance in the "as built" scenario of the existing building, and up to nearly zero energy demand for selected technological solutions applied in specific climatic contexts. In different ways, the results proved that façade additions were very effective; therefore, the additional building envelope is a powerful technological solution combining the improved energy performance of the buildings with a new aesthetic/formal quality.

2.3. User Oriented Requirements

Last, but not least, the increased value of the buildings and the users that can benefit from the extended space, is quite clear. The resulting building may finally provide:

- comfort for users (combined with a proper ventilation system); and
- increased attractiveness even from social sectors that are usually more reluctant to change like elderly inhabitants, providing them with balconies and loggias for small individual gardens.

Potential problems that can be expected in terms of daylight reduction can be tackled by evaluating the appropriate depth of GET structure, the use of highly reflective surfaces for the internal coatings, the potential application of solar pipes to achieve visual comfort, and energy requirements while maintaining the seismic improvement. Thermal bridges are also foreseen. Thus, effort will be concentrated in searching for adequate materials and/or geometrical features for the structural joints to minimize thermal bridges while preserving the necessary structural cohesion. Depending on the original structural performance of the building, the structural frame can be designed according to different geometrical solutions and materials (aluminum, steel and wood). Figure 6 outlines different possible solutions of additional structures on the existing building's envelope.



(a) (b) (c)

Figure 6. Interactions between the existing façade and the steel aluminum structure (**a**); the possible positioning of ducts/pipes/storage (**b**); and the same external structure in timber or X-Lam structure (**c**). Different options for enclosures on the steel/aluminum.

To sum up, rather than the innovation in products, the Pro-GET-onE innovative aspect relies on the approach of the user and the building at the center of the energy retrofit to successfully implement energy strategies and solutions for deep renovation.

2.4. Economic Viability of the GET System

Undoubtedly, the GET systems will be characterized by higher up-front costs with respect to a deep energy renovation. Nonetheless, if we consider the associated costs for seismic retrofitting in the case of a standard seismic renovation, the GET system can produce a significant cost saving. In fact, in the proposed strategy, the avoided disturbance for residents and the moving costs for an average cost reduction of the GET system must be considered and compared to the case of the standard seismic and energy retrofit.

The comparison between the estimated unit costs/time (indicative costs) of a typical deep renovation and the GET system is presented in the following table (Figure 7). The various interventions were divided into the three main requirements of the project: the energy renovation, structural safety, and limited disturbance to the users.

Pro-GET-onE meets the target of 15% of cost reduction when compared to a typical renovation (i.e., renovation that meets the minimum energy and seismic safety requirement). In particular, this is achieved by summing up the construction costs of:

1. Energy renovation: the standard renovation costs are estimated at around 360 euro/m^2 when compared to Pro-GET-onE where the renovation costs are 380 euro/m^2
2. Structural safety: the standard renovation costs are estimated around 390 euro/m^2 when compared to Pro-GET-onE where the renovation costs are 330 euro/m^2
3. Inhabitants' relocation: the standard renovation costs include a quota of 100 euro/m^2; this cost is avoided through Pro-GET-onE, which allows the inhabitants to stay in the building during renovation. The actual cost reduction is therefore about 16.5%. Moreover, it is also significant to consider the added value in economic terms consisting of the extra surface generated by the Pro-GET-onE system. The real estate increased unit value has been evaluated to be around 130–180 euro/m^2 depending on the different regional markets. This consideration reduces

the payback time and increases the impact of the project on the economical side. It can be stated that Pro-GET-onE achieves a unit cost reduction of up to 32–38% when compared to a typical renovation.

	TYPICAL DEEP RENOVATION			PRO-GET-ONE SYSTEM RENOVATION		
MEET ENERGY REQUIREMENTS	INTERVENTIONS	Cost €/m²	Days	INTERVENTIONS	Cost €/m²	Days
	External thermal insulation + finishing systems	60	90	PRO-GET-ONE standard system (structural not included)	90	60
	Windows replacement	70	30	Windows replacement	80	30
	HVAC and water heating system improvements/replacements	80	90	HVAC and water heating system improvements/replacements, plug and play	80	60
	Related demolitions and reconstructions	30	30	Related demolitions and reconstructions	0	0
	Scaffoldings and safety installations	30	240	Scaffoldings and safety installations	10	0
	New renewable energy systems	100	30	PRO-GET-ONE standard renewable energy systems	100	30
	TOTAL CONSTRUCTION COSTS AND DURATION	360	240	TOTAL COSTRUCTION COSTS AND DURATION	380	60
	Maintenance and replacements (25 years cycle, heating/cooling running costs not included)	135	---	Maintenance and replacements (25 years cycle, heating/cooling running costs not included)	115	---
MEET SAFETY REQUIREMENTS	INTERVENTIONS	Unit Cost €/m²	Days	INTERVENTIONS	Unit Cost €/m²	Days
	New reinforced concrete structures (e.g., shear walls) + foundations	350	180	PRO-GET-ONE steel and wood structure + foundations	320	60
	Demolitions and reconstructions related to new structures (e.g., floor replacement)	40	60	Demolitions and reconstructions related to new structures	10	10
	TOTAL CONSTRUCTION COSTS AND DURATION	390	240	TOTAL CONSTRUCTION COSTS AND DURATION	330	70
	Maintenance and replacements (25 years cycle)	5	---	Maintenance and replacements (25 years cycle)	25	---
MEET USER REQUIREMENTS	INTERVENTIONS	Unit Cost €/m2	Days	INTERVENTIONS	Unit Cost €/m²	Days
	Inhabitants relocation (no tailored design)	100	360	Inhabitants relocation (user-oriented design)	0	0
ALL REQUIREMENTS	TOTAL CONSTRUCTION COSTS	850		TOTAL CONSTRUCTION COSTS Per m² of existing UFA	710	
				TOTAL CONSTRUCTION COSTS Per m² of existing UFA plus extra surface (+20% of UFA)	560	
	LIFE CYCLE COSTS (after 25 years, excluding energy running costs)	990		LIFE CYCLE COSTS (after 25 years, excluding energy running costs)	850	
	EXPECTED REAL ESTATE VALUE AFTER INTERVENTION	+15%		EXPECTED REAL ESTATE VALUE AFTER INTERVENTION	+50%	

Figure 7. Comparison of construction unit costs between a typical and GETs deep renovation.

3. Results of a Case Study

One of Pro-GET-onE feasibility studies was located in Greece, more precisely in Peristeri, a suburban municipality of Athens in the Attica region. It has a population of 146,000 inhabitants and is located at a distance of 5 km in the western part of Athens and is the biggest and the second densest suburb of the Attica region. The pilot case of the Peristeri compound (Athens, Greece) is a typical social housing development from the late 1960s.

The main structure of the buildings is reinforced concrete (pillars and beams), concrete slabs, and hollow brick external walls. This is a typical construction typology and is globally presented in all Attican suburbs and the city center. It also has a common structure with similar building blocks all over Europe.

Each building block has a centralized heating system plant. Existing windows are made of an aluminum or wooden frame with single glass although part of the external windows has already been replaced. The energy performance of the buildings is very low and in need of energy retrofit (160 Kwh/m^2 × y (winter)/110 Kwh/m^2 × y (summer)).

The majority of these buildings are residential use with the only exception being the building block (B6) where small businesses shops, offices, and retail are located at the ground floor level. Ownership is 100% by private owners. In total, there are 550 apartments while the average heated residential area per unit is 85 m^2 (Figure 8).

Figure 8. Peristeri urban compound where is located the feasibility study.

A retrofitting project that can guarantee a high level of energy performance can be a source of savings for the inhabitants and municipalities. High-energy costs have led the majority of the residents to choose alternative and less efficient heating solutions such as kerosene, electricity, coal or wood, increasing environmental pollution. The large number of standardized multi-apartment residential blocks leads to the possibility of adopting similar solutions to improve energy efficiency, thus ensuring an economy of scale.

The building identified in compound (A7) is the one outlined in red in Figure 8.

The application of the project could guarantee a substantial energy improvement and would not be limited to this aspect. As we have already seen, the benefits of the "GET" structure would span the improvement of earthquake performance, which is a fundamental aspect to increase the value of the intervention.

Regarding the seismic classification of Greece, as for the Italian case, the territory is divided into zones. The four zones that were created are characterized by a probability of excess of 10% in a reference period of 50 years and a return period of 475 years (PGA values assigned to areas with soil type A). Figure 9 and Table 4 show the seismic subdivision of the territory as reported in the Greek standards, EAK 2000 [14].

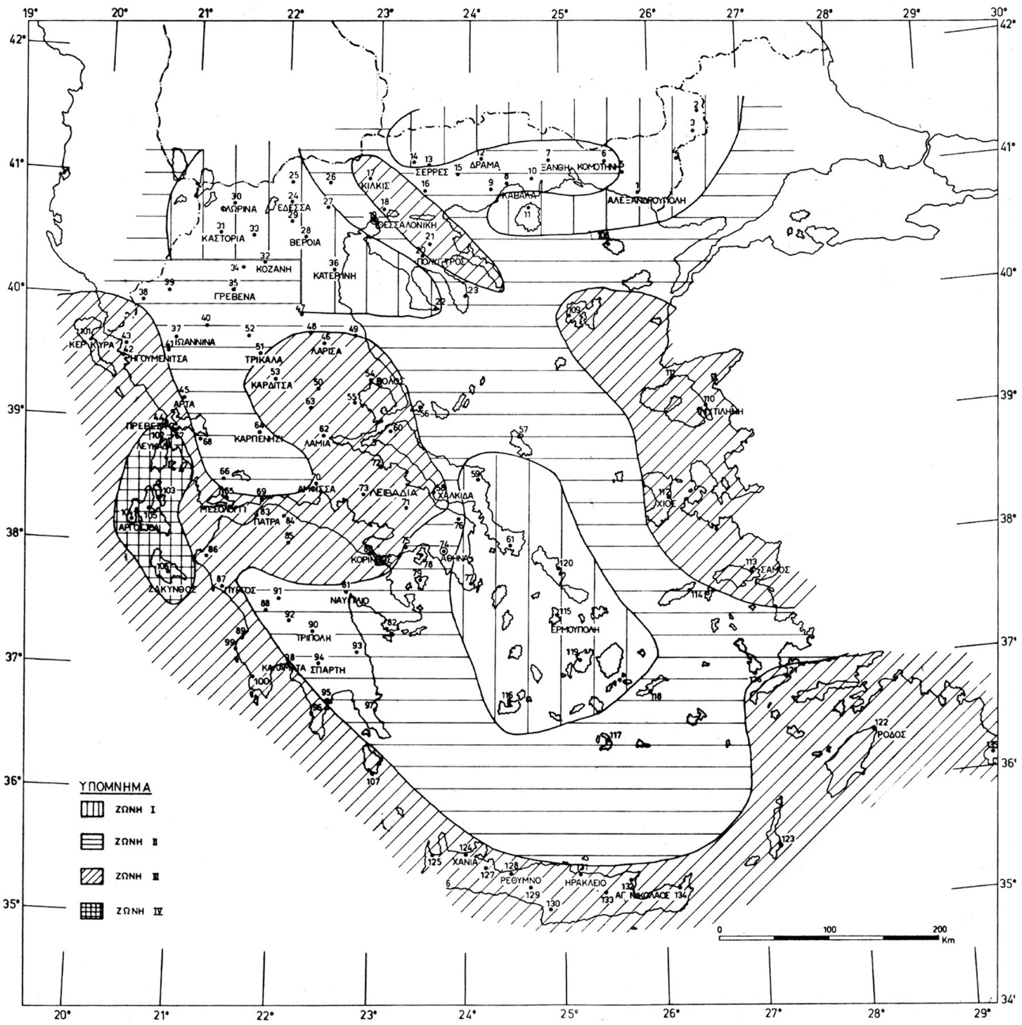


Figure 9. Seismic areas of Greece, as reported in EAK 2000 [14].

Table 4. Subdivision of the seismic areas of Greece.

Seismic Zone	Anchor Acceleration Values
I	0.12 g
II	0.16 g
III	0.24 g
IV	0.36 g

Following this classification, Athens is located in Zone II with an anchor acceleration value of 0.16 g to be applied in the definition of the response spectrum to carry out the checks. In the analysis phase, the structure was subjected to a greater acceleration to highlight the results of the system.

3.1. Seismic Analysis

The building is from the 60s and has a longitudinal shape with a reinforced concrete structure. It was built in the period after World War II when there was a "boom" in construction of this type in the suburbs of all European cities. Unlike the Italian case, despite the construction period, this building testifies to the already present conception of seismic design, as demonstrated by the dimensions of the structural elements.

It has a reinforced concrete structure with a mainly longitudinal development. It is composed by frames arranged in the direction of the shorter side. The concrete slabs lie on these frames. There are also two secondary frames on the edges and one in the middle characterized by the presence of flat beams. A twenty-centimeter reinforced concrete wall can be identified near the stairwells and the elevators.

The original geometrical and architectural data of the initial state were provided to the authors by the municipality of Peristeri. The dimensions and the structural schemes of the beams were obtained by photographic survey, while those of the columns and of the concrete walls were taken from the original architectural plans.

The structure is composed of six units with an average span 6.60 m in the longitudinal development, (the two external ones are of about 6.55 m while the four internal ones have a distance of 6.8 m).Transversely, the space is divided into two zones of a spacing of 3.25 m and 6.05 m. On the ground floor is the *pilotis* while the six upper floors are dedicated to residential units (Figure 10).

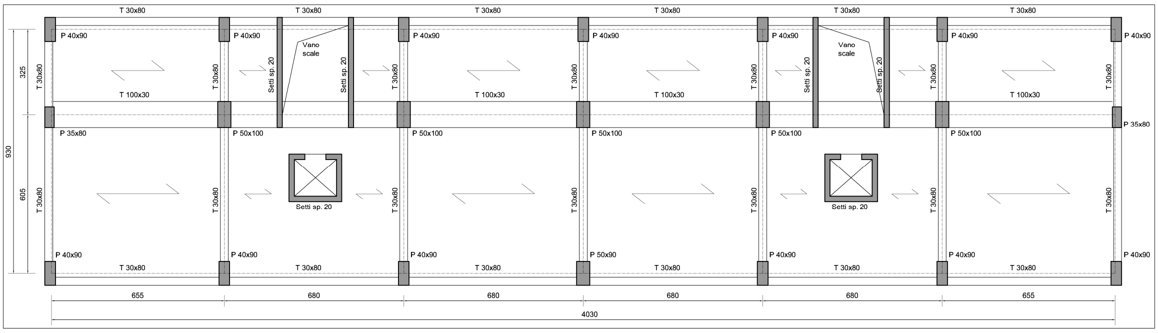


Figure 10. Structural plan—Type plan.

The simulations carried out were done with finite elements software SAP2000 [15]. Linear dynamics (modal analysis with response spectrum) was chosen for the seismic analyses. Table 5 shows data regarding the modeling phase, while Table 6 indicates the seismic parameter for the response spectrum definition for the analyses and for the verifications.

Table 5. Modeling data.

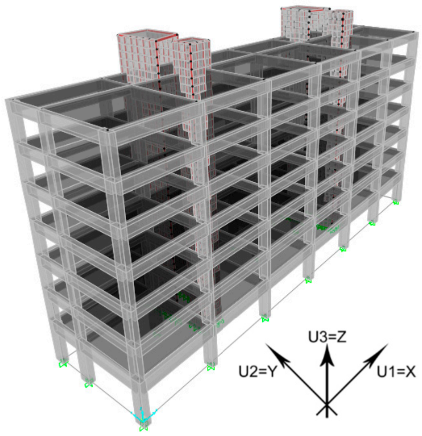
Analysis	Linear Dynamics
Modal combination	CQC (§ 4.3.3.3.2 Eurocode 8)
Eccentricity value	5%
Directional combination	$1.00 \cdot E_x + 0.30 \cdot E_y + 0.30 \cdot E_z$
Limit state	Significant Damage—SD
Behavior factor	$q = 2.00$
Reference parameters in assessments	Maximum absolute displacements—δmax Structural period—T1

Table 6. Seismic parameters for the definition of the elastic response spectrum.

Analysis
SLV (SD)—P_{VR} = 10%; T_R = 475 years; V_R = 50 years • $a_g/g = 0.259$ • $F_0 = 2.363$ • $T_C = 0.342$
Verification—Seismic Zone II (EAK 2000)
SLV (SD)—P_{VR} = 10%; T_R = 475 years; V_R = 50 years • $a_g/g = 0.16$

In this section, we refer to two parameters regarding the results of the proposed structure: the absolute displacements at the top of the existing building, and the period of the structure.

The assumed structure composed briefly as shown above in the structural plan was modeled in SAP2000 [15] through the use of linear elements (for beams and columns) and bilinear elements, shells (for concrete walls). Figure 11 reports the main results of the linear dynamics analysis of the initial state.



	U1 (m)	U2 (m)
δmax	0.0874	0.0763

	T—Period
1° MV	1.004

Figure 11. Displacements and structural period of the linear dynamics analysis of the initial state.

Regarding the building's seismic response, it is evident that it was designed to withstand seismic actions. In fact, despite the high level of the applied seismic action, there are limited displacements considering the height of the building. From the analyses carried out after the application of the "GET" system, it was therefore predictable to obtain very limited improvements when compared to the virtual cases previously described.

The additional structure provided for the project consists of steel frames (columns and beams) for each floor, braced in the transversal direction due to the architectural requirements, and linked to the joints of the existing reinforced concrete frame (created from the intersection of beams and pillars). These frames are also connected in the longitudinal direction to create a spatial frame interconnected with the existing structure.

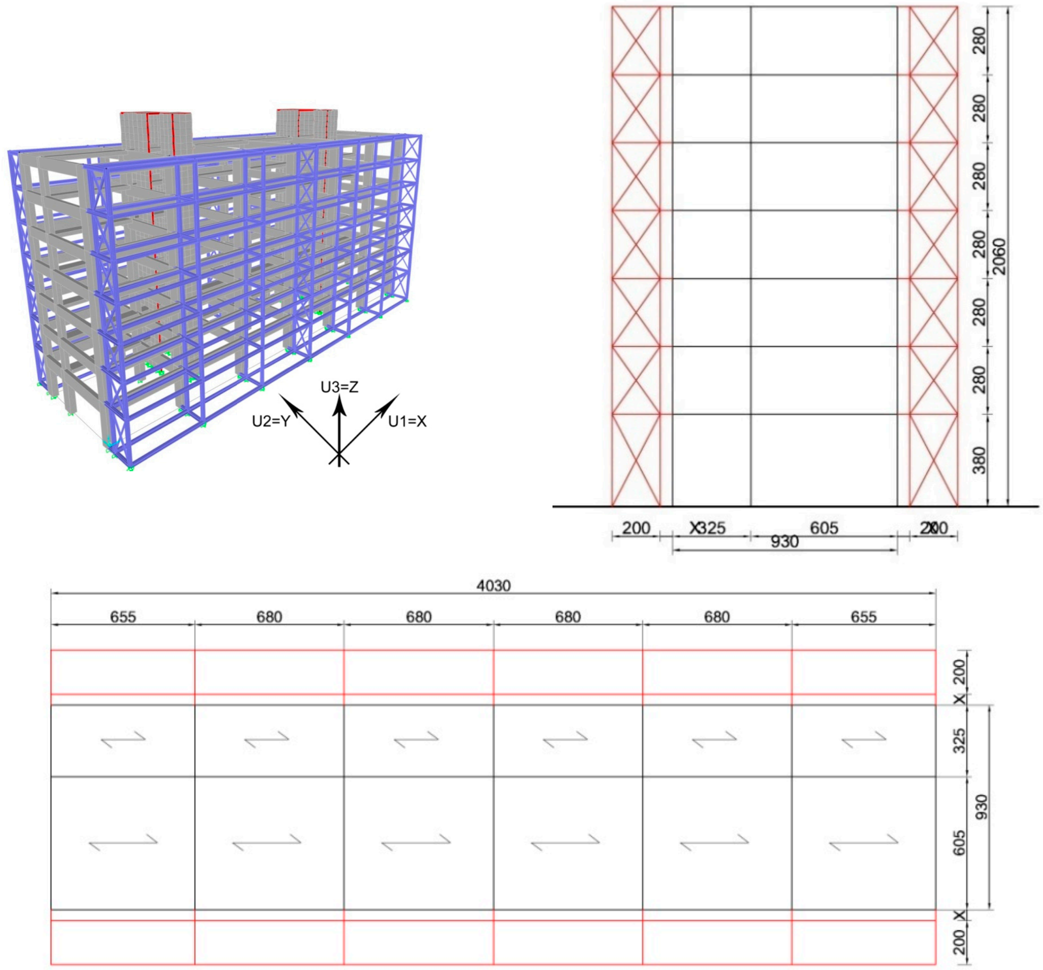
The depth increase of the smaller side of the building allows it to obtain more regularity in plan and to increase the stiffness, causing a reduction of displacements and internal forces in the elements.

The first steel structure solution (solution A, shown in Figure 12) is continuous on the whole façade and presents transversal bracing at the middle and at the ends of the new structure.

Here we show the results due to the variation of the profiles that compose the structure (columns and beams). The improvement is calculated on the comparison before and after the application of the steel structure.

In this phase, several profiles were examined initially by varying the type at the same weight and subsequently by varying the type with the same height in order to obtain a general scheme. Based on these analyses, the incidence of the profiles has been verified.

It has been verified that the choice of the columns is decisive in the improvement and that the types of profiles that have a different inertia module in the two directions (e.g., IPE type) are inconvenient. In fact, in some cases, these profiles aggravate the displacements in the longitudinal direction. The other way around, profiles with equivalent stiffness or almost in the two directions are ideal for the intervention (HE and pipes). Clearly, HE profiles are preferable during the assembly procedure.



SD	U2 (m)	-Δ- U2 (%)	U1 (m)	-Δ- U1 (%)
I.S.	0.076	**-**	0.087	**-**
-Δ- min.	0.071	**7.60**	0.090	**−2.56**
...	...	**...**	...	**...**
-Δ- MAX.	0.059	**21.49**	0.079	**8.58**

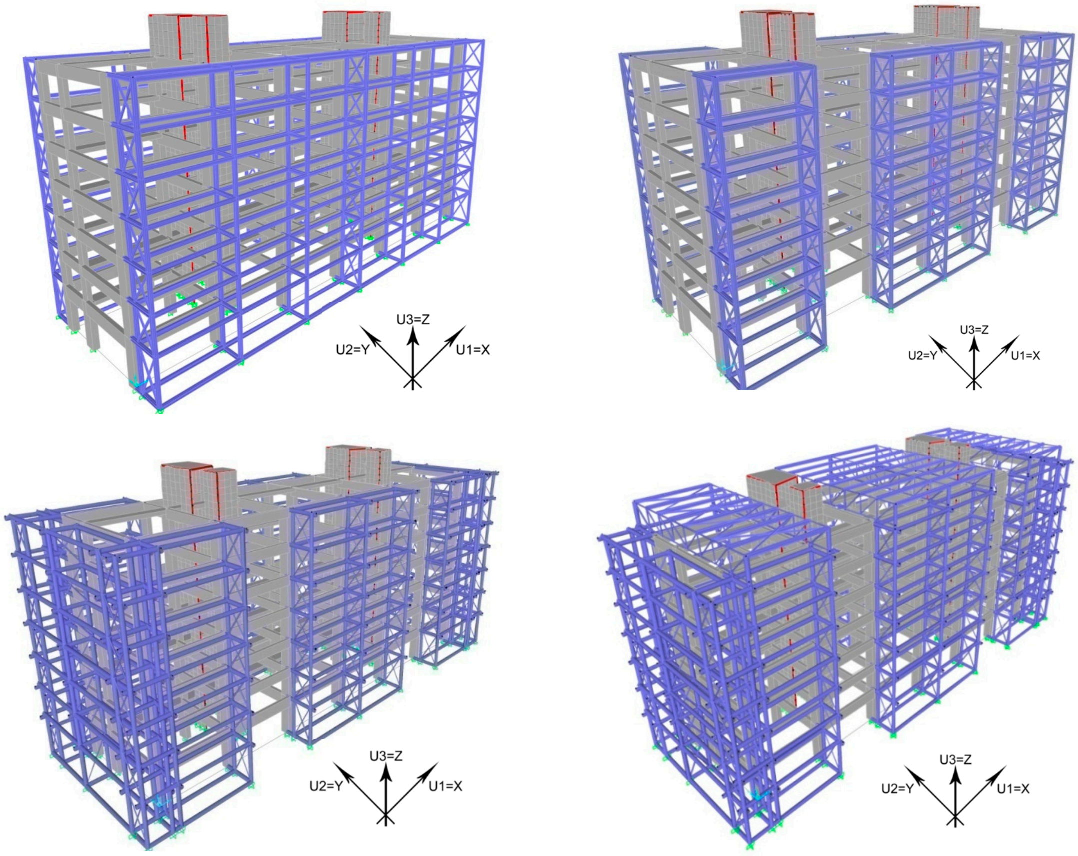
	T—Period	-Δ- T (%)
I.S.	1.004	-
-Δ- min.	1.097	−8.48
...	...	...
-Δ- MAX.	0.955	4.88

Figure 12. Finite element model of solution A, structural schemes of the new external structure and results in displacements and periods.

The following analyses were carried out with the use of HEB 240 and Φ323.9/12 profiles. The results obtained using the last indicated profile are shown below, but follow different structural configurations as described in Section 2.1:

- A—Continuous addition to the longitudinal façades. It presents transversal bracing at the middle and at the ends of the new structure.
- B—Alternate addition to the longitudinal façades. It presents transversal bracing at each span.
- C—Alternate addition to the longitudinal façades combined with continuous addition on the transversals.
- D—Alternate addition to the longitudinal façades, continuous addition on the transversals plus top connection with reticular beams.

Looking at the results obtained from the analyses (Figure 13), design solution B had more diagonal bracing on the transversal planes and smaller displacements in the Y (U2) direction. Moreover, this solution turned out to be the least expensive by using lower quantities of steel in the project.



SD	U2 (m)	-Δ- U2 (%)	U1 (m)	-Δ- U1 (%)
I.S.	0.076	**-**	0.087	**-**
Sol. A	0.062	**19.14**	0.081	**6.98**
Sol. B	0.059	**22.81**	0.082	**6.64**
Sol. C	0.057	**24.77**	0.077	**12.6**
Sol. D	0.057	**26.0**	0.077	**12.6**

	T—Period	-Δ- T (%)
I.S.	1.004	**-**
Sol. A	0.977	**2.69**
Sol. B	0.974	**2.99**
Sol. C	0.926	**7.8**
Sol. D	0.933	**7.1**

Figure 13. Finite element model of solution A, structural schemes of the new external structure, and results in displacements and periods.

Solution C had an alternate addition to the longitudinal facades and a continuous addition on the transversals. The addition on the short sides was not connected to the existing structure, but only to the longitudinal ones. This helped to improve the performance of the structure in both directions to the detriment of an increase in costs countered by a small increase in useful area.

The last solution of the analysis phase provided a superior connection between the lateral additions, which produced a decrease in displacements against an increase in the period due to the rise in building height.

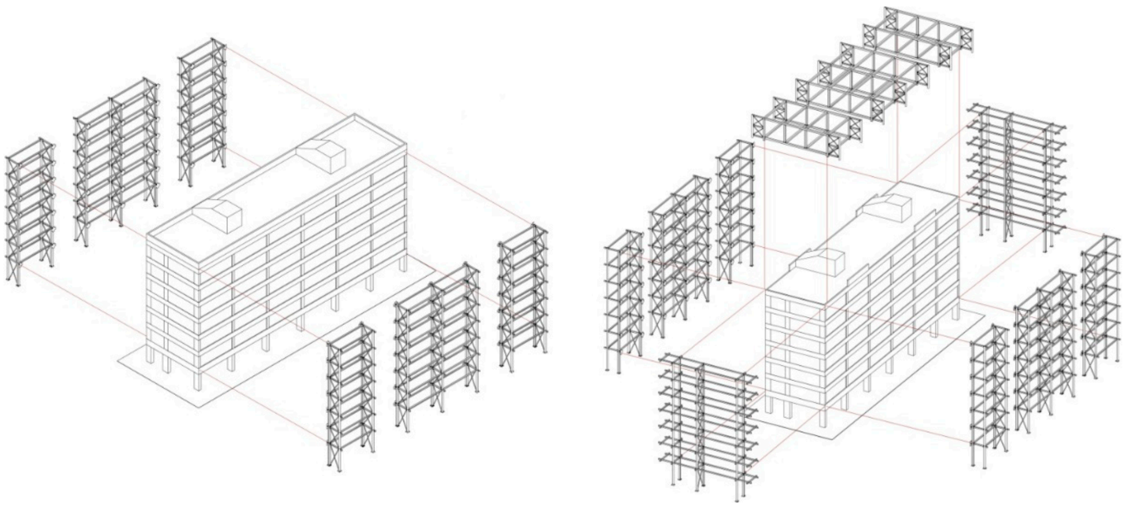
Finally, by also combining an assessment of the costs of the structure, a check of the elements of the new steel frame was carried out. In this phase, all the profiles constituting the new structure were defined and differentiated based on internal stress and on the cost calculation dependent on the weight of steel. The aim was to find a fair compromise between the construction costs and performance in terms of improvement achieved on the existing structure.

Another fundamental aspect was represented by a parallel evaluation of the added surfaces due to the volumetric external addition. The added value given by these areas reduced the expenses.

As reported at the beginning of the section regarding the verifications (Eurocode 3 and 8), the seismic load relating to Athens was used based on the EAK2000 [14].

Two structural solutions were considered due to different benefits:

- B1—Alternate addition to the longitudinal façades (Figure 14a). This solution involves the greatest performance benefit with minimal cost; however, it has a small contribution in terms of added area.
- E1—Alternate addition to the longitudinal façades, continuous addition on the transversals plus top connection with Vierendeel beams (Figure 14b). A different solution to the previous ones is illustrated below. Thanks to the possibility of raising the structure of a floor, this allows the greatest contribution in terms of added surface, a higher cost with equal performance benefit on displacements.



(**a**) (**b**)

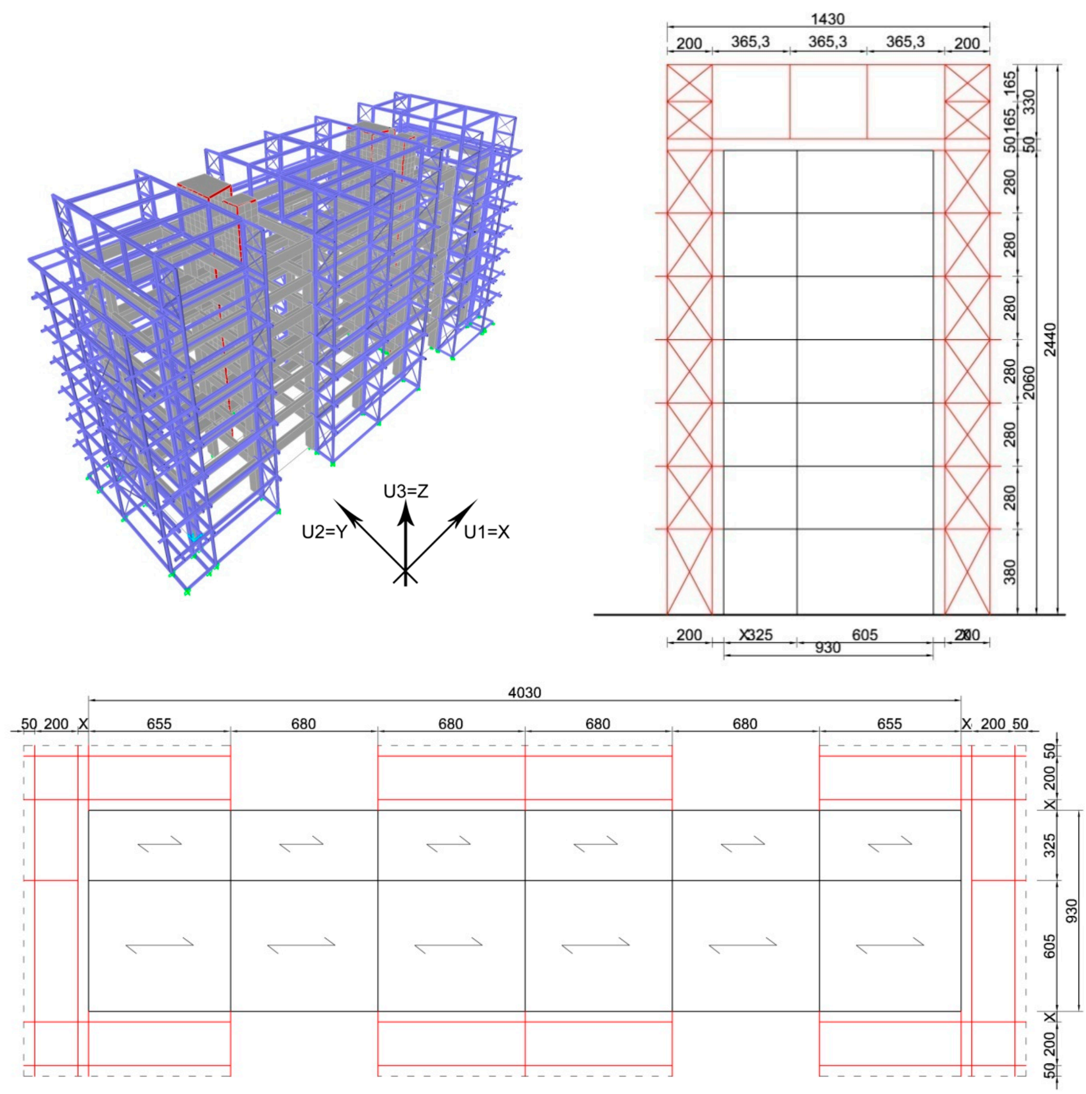
Figure 14. Axonometric drawings of the two selected solutions. On the left (**a**) is presented the alternate addition to the longitudinal façades B1, while on the right (**b**) there is the alternate addition to the longitudinal façades, continuous addition on the transversals plus top connection with Vierendeel beams E1.

Regarding the design solution E1, Figure 15 shows the schemes and the analyses output data.

Furthermore, the actual benefit that the Pro-GET-onE implies for the existing construction in terms of earthquake response was verified. Various design solutions were analyzed that involved variable quantities of added area, and used material (steel), which produced different responses to the earthquake. Overall, an improvement in terms of displacements was always obtained due to the increase in stiffness given by the addition of the new structure. The analysis carried out initially focused on the maximization of the benefits on the existing construction and afterwards, on the most valid design solutions (in terms of performance), a compromise has been proposed to ensure a seismic improvement at the lowest possible construction cost (considering only the structural components of the project).

Two proposals have been made (B1 and E1), which guarantee good performance in terms of transversal displacements (16–17% improvement), a substantial indifference for the displacements in the longitudinal development of the construction, and a large increase in added surface that reduced the cost of construction. Additionally, the assessments on the construction cost showed that both solutions had the same cost per square meter of added surface.

In conclusion, as far as regarding seismic safety, this case study verified that the GET system could provide improvements even for buildings that have already been designed with an adequate performance for horizontal loads. Certainly, the value of improvement for the previous buildings mentioned, was limited when compared to the structures that have been designed to withstand only vertical loads, in which cases the GET system could prove better safety results.



SD	U2 (m)	-Δ- U2 (%)	U1 (m)	-Δ- U1 (%)
I.S.	0.0305	-	0.0341	-
Sol. B1	0.0255	**16.40**	0.0337	**1.17**
Sol. E1	0.0253	**17.05**	0.0335	**1.76**

	T—Period	-Δ- T (%)
I.S.	1.004	-
Sol. B1	1.025	**−2.05**
Sol. E1	1.083	**−7.29**

Figure 15. Finite element model of solution E1, structural schemes of the new external structure, and results in displacements and periods.

3.2. Architectural Verification—The Abacus

Parallel to the seismic improvement conferred by the external steel structure, a series of possible architectural solutions have been developed to incorporate the skeleton initially formed by the single structural component. In this phase, it is necessary to consider several factors that determine the appearance and the way of using the additional space by choosing constructive solutions, materials, and the functional types. Highlights of this design typology include the versatility of the additional volumetric units in relation to the possibilities and the choices of the user, and the constant search of energy improvement aimed at the goal of bringing the existing building toward the nZEB.

Currently, one of the main shortcomings of deep retrofitting towards nearly zero energy is that they generally rely on separate clusters of technologies that are difficult to integrate. To overcome these barriers and create a roadmap for cost effective renovation through a well-balanced strategy of mass customization, the research project has envisaged an integrated modular system, composed of components manufactured off-site, that can be customized and optimized for different cases in a user-oriented perspective (by adding balconies, loggias, sunspaces according to the users' needs and expectations). The integration of the system will focus on the interfaces between the different components to ensure their collective performance according to the project requirements. Standardized interfaces will also ensure the flexibility of the system, as different components can be interchanged and adjusted as a function of different climate conditions and urban context, as well as according to the inhabitants' requirement.

Regarding the Greek building, different architectural hypotheses have been realized. In each of these solutions, several additional volumetric units were hypothesized and divided into three functional types: sunspace, extra-room, and balcony. Figure 16 shows a possible functional and therefore architectural variation of the same external volumetric addition.

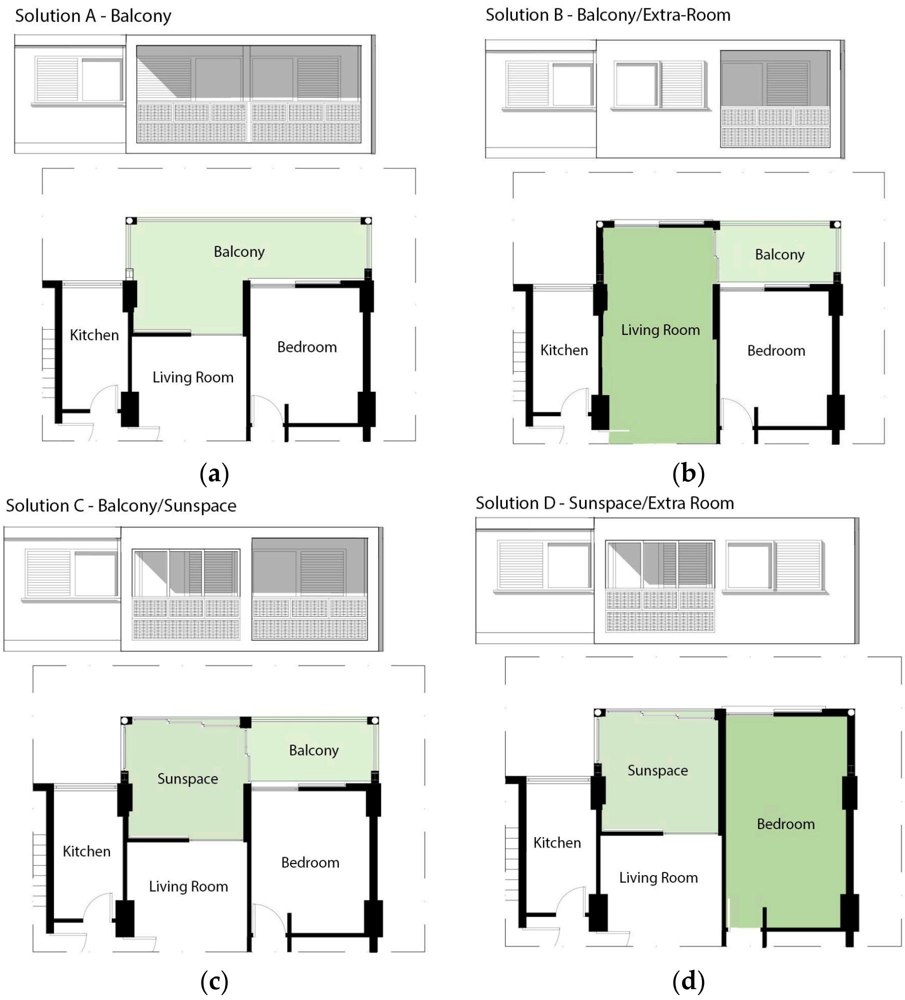


Figure 16. Possible functional variation of the same external volumetric addition made by the alternate combination of sunspace, balcony, or extra-room. Every plan solution determines a different façade conformation. Solution (**a**) refers to an extension with the option of a balcony, where (**b**) is a combination of an extra room with a balcony, (**c**) refers to the combination of a sunspace with a balcony and finally (**d**) is the combination of an extra room and a sunspace.

Performed cost-benefit analysis in a large set of reference buildings in the context of another EU project ABRACADABRA [16] that considered the hypothetic investment in additional units on top of GETs showed that the potential economic gains obtained through the sale would largely compensate the energy retrofit cost including RES to set the energy demand of the whole building to zero. The GET system, in fact, could be used to support additional loads on top of buildings that were not structurally conceived for addition. This aspect could implement and accelerate the market penetration of deep renovation within the private sector, which is the most challenging sector to overcome the existing barriers in energy retrofit market uptake. In fact, energy-retrofitting actions are very often implemented in over-imposed actions by the main ownership, with no direct benefits to the final users.

To overcome this limit, it is necessary to focus on the local private owners of real built environments where owners may directly benefit from the economic and spatial gains. Different options of façade adds-on to be integrated on the vertical surfaces of the existing buildings will be studied and categorized in a comprehensive abacus containing the different solution along with the variable measures/materials/technologies to be adopted. The possible modifications in the façade modules will be studied according the main structural frame and the residential units' utilities.

They will be grouped in one abacus of possibilities that will become one of the main design tools for planners and professionals involved in the GET process. In fact, the abacus can be tailored and customized as a function of different construction elements and architecture in the different case studies and it will represent the catalogue of a new production line for a possible joint participation between SME partners. The abacus is designed to define classification criteria, to launch an open energy performance and architectural repository to be used as an unlocked resource where energy professionals and major users like home-owners, tenants, condominium's administrators, etc. may find technical tools to deep renovate housing residential buildings.

In terms of the architectural solutions, the development phase of the technical solutions for the realization of the horizontal and vertical partitions of the GET system is under process. Therefore, the Peristeri case application is the first approach to this detailed phase of design that will lead to the definition of the integrated technical solution. Figure 17 shows drawings of another example of application.

Figure 17. Façade, plan and detailed section of a typical application of the GET system on the Peristeri building.

Different material, technical, and functional choices involve different compositional solutions. On the basis of the design hypotheses carried out on the Peristeri case, perspective views have been made of what may result following the realization of the Pro-GET-onE (Figure 18).

Figure 18. Possible façade verification of the application of the GET system on the Peristeri building.

Outstanding examples in architecture building practice so far that could be considered as the inspiration behind the GET strategy include the transformation of the Tour Bois Le Pretre by the French architect Frédéric Druot [17,18]. This is a significant example of deep renovation combining energy retrofit with architectural quality and social sustainability. Another significant example is the extension and refurbishment of the residential Tower Weberstrasse, Winterthur, an existing 12 level apartment tower, built at the 1960s by the architect H. Isler. The project refers to an extension of the rear facade planned by Bulkhalter Sumi architekten [19].

In both examples, the additional space led to the variation of the existing apartments, the increase of a greater sense of security, and at the same time upgraded the social life of the community with the active participation of the owners during the whole procedure. New "envelopes" often consist of architectural spaces and units: the new volumes with the winter gardens, the extra balconies and galleries create a transition zone between the existing building envelope and the external climatic conditions and that results, as reported in the reference cases, in a consistent decrease in the initial energy consumption.

The architectural solutions here described, starting from a non-energy related objective like the increase of the rentable surface and, more generally, the increase of the asset value, prove that technological and architectural transformation in buildings do have the highest potential to decrease energy consumption in the existing ones. Regarding the case study of the Tower Weberstrasse [19], the measured energy consumptions calculated on the heated surface before the renovation (3887 m^2) was calculated up to 604,244 kWh/year. This resulted in 155 kWh/m^2 per year in terms of gas consumption. After the renovation, the calculated energy consumption accounted for a global 61.5 kWh/m^2 per year, considering a total increased surface of 4.830 m^2, thus, including the addition.

4. Field of Application and Potential Impact

The field of investigation and design is limited to existing buildings from the 1950s and 60s onwards. Indeed, this is not an actual limit, since these buildings represent the large majority of the EU building stock and are the biggest source of energy loss. Taking into account that today, only 1% per year of the existing buildings are renovated, it is obvious that these buildings embed a great potential in terms of impact on the building construction sector for energy, architectural, and economical reasons.

The project, by setting the ambitious target of achieving nZEBs in the most critical cluster of buildings (the building blocks from the 1970s onwards represent the most inefficient buildings located in the poorer and seismic areas of the Mediterranean) addresses:

- The large majority of urban areas in the EU; as reported in noticeable studies in the EU 27 the peri-urban areas represent the larger majority with respect to the central urban areas. Indeed, recent studies [20] have revealed how dense peripheral contexts preserve large areas for possible densification.
- The large majority of the EU building stock. As a matter of fact, about 70% of buildings in the EU have been built after the Second World War (60s to 90s) and well before the entry into force of regulatory measures on energy consumption reduction [21].
- The most inefficient buildings in all their different sizes and type (single family houses, multifamily houses and high-rise buildings);
- Buildings where change and transformation are feasible (due to free or available areas) and beneficial for energy, architectural, economical, and social reasons.

Furthermore, Pro-GET-onE aims at addressing a large sector of the residential stock: the ones owned by owner-occupiers, private landlords, and social housing companies. In particular, the proposal largely aims to address the accommodation of almost all EU citizens: indeed just over seven out of 10 (70.6%) people in the EU-28 lived in owner-occupied dwellings, while 18.5% were tenants with a market price rent, and 10.9% were tenants in reduced-rent or free accommodation.

The information required in the design, construction, and operation of facilities from their inception onward, will be based on computer-generated models containing accurate geometry and relevant data needed to support the whole lifecycle of buildings. This concept is referred to as Building Information Modelling, as pointed out by Charles Eastman [22] and by many other scientific works [23–29].

The production process of components in off-site factories, their supply to the construction site, and the onsite assembly procedures will have to be optimized by a BIM-based process to maximize the workflow and project efficiency.

Many firms are already using BIM design to collaborate with general contractors and construction managers, to automate production and prefabricate building components such as mechanical equipment and curtain-wall systems. In Pro-GET-onE, BIM will be exploited as a pipelined process among researchers, designers, managers, engineers, architects, and contractors, all sharing a common language made of digital representations. Three kinds of knowledge will be characterized to properly model the facility: knowledge about object shapes (survey), knowledge about objects identities (metadata implementing), and knowledge about the relationships between elements (BIM semantic modelling aimed at analysis).

This will enable both the minimization of the embedded energy of the system, and the minimization of its costs. The planning, simulation, and optimization of the different processes occurring in building construction will be enabled through the following tools and methodologies:

- A Building Information Modelling (BIM) software platform for pre-production design coordination, interface checking, and clash detection;
- A Process Information Modelling (PIM) framework that combines BIM with an applied kinematics assembly simulation system to simulate and optimize the production processes taking into account the material attributes and production speed. The PIM framework will be descriptive, prescriptive, and explanatory. While BIM is a good approach for these aspects, a wider system of connections has to be layered to become PIM-compliant, so during the executive stage, a proper BIM execution plan will be delivered to implement the advantages of PIM.

5. Expected Future Impact

The current impact of the research project is based on 24 dwelling units of about 100 sqm. each that will be renovated in the Groningen area. Other case studies consist of the project demo-building in Athens (about 2600 sqm.), and a building in the Reggio Emilia district (about 1000 sqm.). In the following years, more than 113 dwelling units will be used as regional specific buildings in the Groningen area. However, to calculate the large scale potential impact of the project, new calculation techniques and methods based on parametric modeling will be developed to improve the speed and efficiency of the calculations for individually different residential buildings and the surrounding available area for different seismic target regions.

The integrated and multi-purpose nature of Pro-GET-onE determines the high level of effectiveness of the proposal. Moreover, the consolidated knowledge used in the seismic technical solution proposed and its combination of different products already available on the market in the definition of a new system are the major outcomes. By assessing and answering—in one prefabricated solution—the energy, structural, and fire safety needs, together with the possibility of integrating the personalization of different components within the same mass-produced product, Pro-GET-onE opens a methodological revolution in the retrofitting practice. This highly innovative and effective technology offers the possibility of re-launching the renovation sector and foster its application on a broader scale in Europe.

The studied solutions aim at enabling the conditions to create attractive, self-financing schemes to support deep renovation actions; in fact, the GET system represents a possible standardized solution with a highly replicable strategy, especially for the Mediterranean countries of the EU and all the induced seismic areas of the EU. It is the authors' considered opinion that this strategy could more easily convince the users, the urban dwellers, and investors in the energy regeneration and major architectural revamp of the existing buildings. This ambitious idea is based on the willingness of creating completely retrofitted buildings that can be admired and looked-for from other condominiums in the surrounding areas and, from them, to many other buildings in the Mediterranean and EU. Moreover, Pro-GET-onE will put in place the legal/economic and social conditions where energy savings, combined with the increased real estate value, can be mobilized to repay a significant part of the energy investments.

The research project aims at ensuring the proper exploitation of a ground-based knowledge to boost the European strategic aim of mobilizing investment in the energy renovation of the existing building stock.

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Author Contributions: As project coordinator, Annarita Ferrante was responsible for the overall research concept, for the definition of the possible architectural choices and for the structure envelope of the GET system. She particularly dealt with the integration between, structural, energy and user oriented requirements related with the architectural improvement of the building. Giovanni Mochi participated in the development of the structural components of the façade addition and he also dealt with the economic viability of the GET System, providing a comparison of construction unit costs between a typical deep renovation and the new GETs. Giorgia Predari was responsible for defining the characteristics of the structural scheme to be adopted to achieve seismic improvement, as part of the multi-benefit solutions. Furthermore, she contributed to the modeling of the existing structure and the steel exoskeleton, with the interpretation of the results as regards the structural part. Lorenzo Badini dealt with the bibliographic research and the definition of the state of the art; additionally he worked on the structural simulations using the SAP2000 calculation software, applying the proposals of the structural schemes to the case study of the residential building in Peristeri. Anastasia Fotopoulou was responsible for defining the energy and user oriented requirements of the GET structure, and she contributed to the drafting of the abacus for the case study of Peristeri, with the definition of the possible functional variation of the same external volumetric addition made by the alternate combination of sunspace, balcony, or extra-room. Riccardo Gulli made its contribution in defining the applicability of the GET system to the existing building made by reinforced concrete and in its expected future impact. Giovanni Semprini was responsible of the plant integration in the volume of the

GET system and how to satisfy the nearly zero energy demand, with energy simulation implemented through calculation software.

Conflicts of Interest: The authors declare no conflict of interest.

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