Intelligent Manufacturing System of LGS Profiles for Green Metallic Constructions

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Abstract: The paper evidences research results on an innovative intelligent manufacturing process and its manufacturing system. The metallic construction, based on steel framing and, consequently, on Light Gauge Steel profiles, has got an increasing attention lately, due to their specific features that involve environmental friendly building technologies, process efficiency and, last but not the least, relatively low costs. A metallic construction has a steel framing structure, similar to that of wood, but is lighter and easier to build, not to mention that it is recyclable waste. It is based on LGS profiles, that are manufactured by cold plastic deformation process of relatively low carbon steel. In order to improve the profile's material mechanical characteristics, induction hardening process is introduced, distinctly, during the whole manufacturing process stages. Thus, it is estimated a reduction of material consumption, about 10 % and, consequently, a reduction of construction costs by 7%.

1 INTRODUCTION TO LIGHT GAUGE STEEL FRAMING

High industrialization and intensive use of natural resources have caused severe climatic changes that impact, not for the best usually, so many people's lives. Against this backdrop, there comes the need of building constructions in a wise way, to be able to have as much affordable space as possible in a given perimeter, to be safe and sustainable, not to mention to have as many recyclable materials as possible. First in the USA, rather than in Europe, steel framed construction has been and extended, so that, an interesting and promising market is available.

Characteristics, benefits and limitation of this type of buildings are presented further in this paper. Still, the focus is on the research developed in order to improve the mechanical characteristics of the steel in profiles called Light Gauge Steel (LGS) profiles.

As mentioned in (www.designingbuildings.co.uk), light gauge steel framing systems consist of structural frames made of cold formed steel sections. They can be used throughout a structure, including load-bearing exterior walls, non-load bearing interior walls, floor joists, curtain walls and roof trusses.

Factors that led to the use of LGS frames in buildings (Yandzio, et al., 2015) are these: environmental necessity to preserve use land; efficient and sustainable construction process; adaptability to provide more adaptable use of space.

Some methods of building light gauge steel framed constructions are as follows: stick-build construction, when discrete elements are assembled

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on-site; panel construction, when wall panels, floor cassettes, roof trusses etc. are manufactured in a factory and assembled on site; modular construction, when units are completely manufactured in a factory and, further, delivered to site.

Lightweight steel framing (LSF) constructions do present many specifics advantages, as many specialists mention.

For example, Claudio Martins (Martins et. al, 2013) emphasizes the thermal performance of LSF elements (made of Light Gauge Steel profiles) focusing on available strategies for the mitigation of thermal bridges, such as: keep the facade geometry as simple as possible; avoid the interruption of the insulated layer; the insulation layers to be joined at full length, etc.

The steel producer, ArcelorMittal (https:// constructalia. arcelormittal.com) states that the light weight steel frame house is very efficient, from the sustainability point of view. That is due to the fact that steel is 100% recyclable and almost 80% of the steel in construction comes from recycling. Moreover, the structure is light and can be built on less foundation on regular, or even, poor soils.

In the project Waste Reduction Potential of Light Steel Frame Construction (WAS 003-003) there are mentioned the principles of the lean process and their impact on the waste minimisation potential of the offsite manufacture, which are focused on the manufacturing processes of the LSF elements for walls and floors, as shown in Table 1.

A lightweight steel framed construction is safe in case of earthquakes, usually in higher degree than a common (wood) construction, due to specific features as the ones that follow next (http:// www.steelframing.org/earthquake).

-Steel is a stable material with consistent chemical attributes and once the steel stud has been formed, it will remain straight with virtually no change to the thickness, width or other dimensional properties.

- Steel frame is typically one-third the weight of a wood frame and, consequently, damage through "inertia" will be significantly reduced.

- Steel framing is impervious to rot, termites and other pests that can slowly degrade the structural integrity of the framing members, lessening the ability of a house to withstand seismic forces

A study on the seismic behavior of the steel lightweight structures, has been developed in the ELISSA project (Landolfo R, 2018) . It is mentioned that all the steel structures could be designed according a DCL (low dissipative approach for low seismicity zones) by assuming the behavior factor equal to 1.5. Still, this approach may be restrictive, since the lightness of lightweight systems also makes them a good solution for high seismicity zones. Some relevant results of this research are shown in Figure 1.

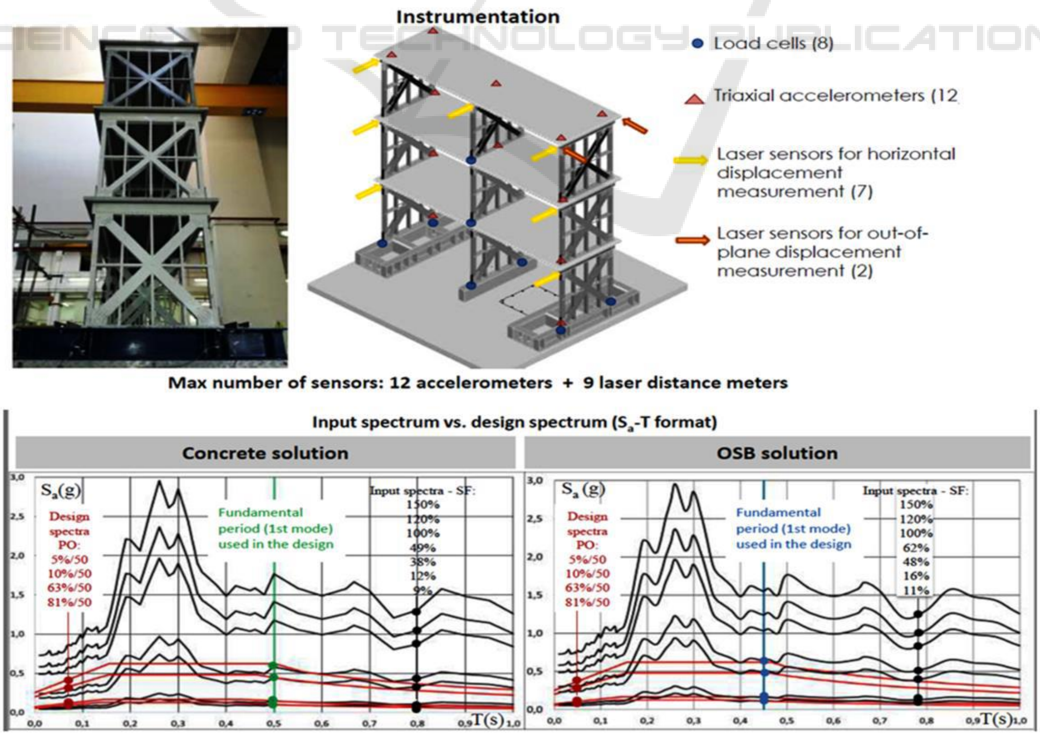


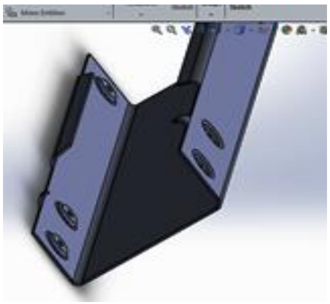
Figure 1: Seismic behavior of lightweight structures. (Landolfo R, 2018).

Table 1: Summary of saved materials and waste generated. (WAS 003-003).

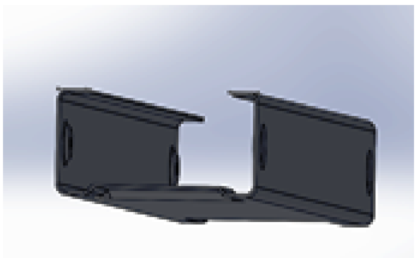
Activities	Waste generated		Waste disposal (%)			Saved Material (%)
	Type	%	Reuse	Recycle	Landfill	
Design						
accurate engineering	None	-/-	-/-	-/-	-/-	Steel (-5%)
Chipboard cutting patterns	None	-/-	-/-	-/-	-/-	Timber (4%)
Process Review – Optimisation of rolling machinery	None	-/-	-/-	-/-	-/-	Steel (-6%)
Procurement						
Pre-cut steel joists for floor cassettes	None	-/-	-/-	-/-	-/-	Steel (15%)
New rivet sizes	None	-/-	-/-	-/-	-/-	Materials (-12%)
Manufacturing						
Steel structural member rolling process	Steel	1%	Fraction	100%	0%	-/-
Floor decking	Timber based	5%	100%	0%	0%	-/-
Shipping						
Use of recycled timber pallets returned to factory	Timber based	0%	100%	0%	0%	-/-
Packaging use of re-usable stillages	None	-/-	-/-	-/-	-/-	Plastic / timber pallets/ etc.
Optimisation and planning of transport (grouped consignments)	None	-/-	-/-	-/-	-/-	Lorry Movements (-8%)
Erection						
site activities	Steel	0%	0%	0%	0%	-/-
	Insulation	12%	95%	5%	5%	-/-

3 INTELLIGENT INNOVATIVE MANUFACTURING SYSTEM FOR LGS PROFILE

Lightweight steel framed constructions have as basic element the light gauge steel (LGS) profile, usually of C, or U type cross section. Depending on their position within the structure and, consequently, on its loading, the shape and dimensions of the LGS profile varies – see Figure 2. For this research, it has been considered of interest to study the C shape profile, with 420 mm length – due to the high loading stress when used in trusses and studs.



U / C type LGS profile 300 mm length



C type LGS profile

420 mm length

Figure 2: LGS profile type.

LGS profiles are made of steel with relatively low carbon percentage, delivered as tape coil, previously galvanized. Images of LGS profiles are presented in Figure 3.

LGS profiles

LGS profiles assembled

Figure 3: LGS profile.

The basic manufacturing process for LGS profiles is that of cold plastic deformation. Mainly, from strip coil, in successive stages, starting from flat shape (coil material) final profile cuts, wholes and side bending are obtained. For the studied C type LGS profile, of 420 mm length, conventionally called C420, the technological scheme is shown in Figure 4.

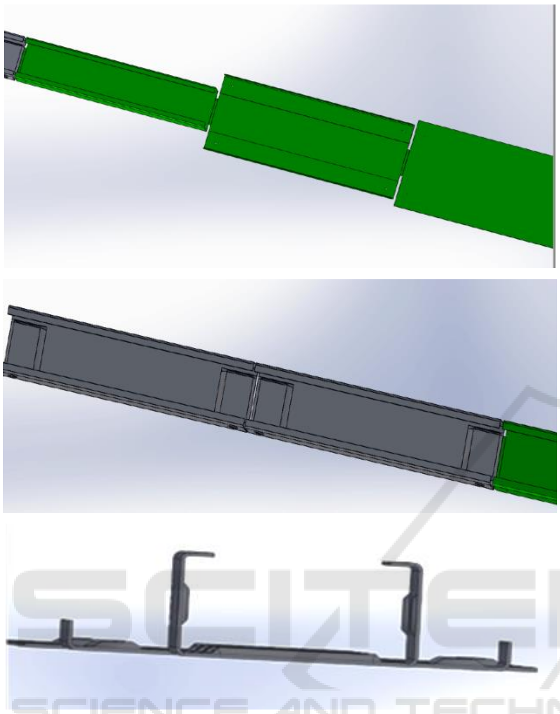


Figure 4: LGS profile cold plastic deformation.

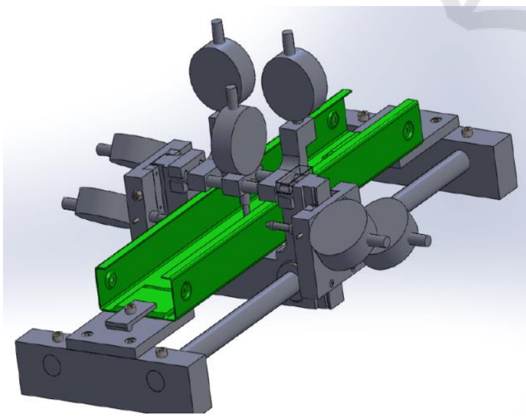
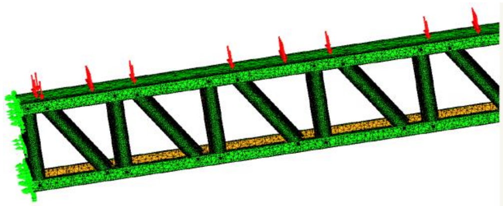


Figure 5: Control device for LGS profile.

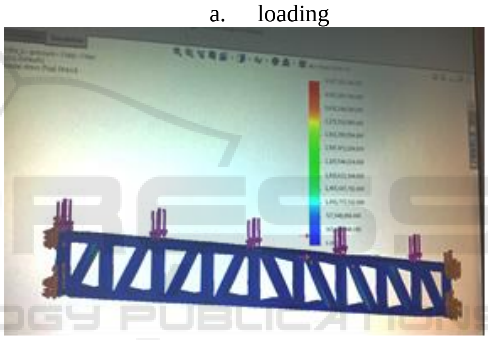
Even if it is assumed that the geometric precision of the LGS profile stands within the prescribed tolerance, there has been designed a device checking the resulting dimensions, shape and position of the relative surfaces (after the cold deformation process) of the profile (Figure 5).

This device is basic, either portable, or fixed, for profiles not longer than 700 mm (420 mm being the length of the C420) and fit for further automation and computer assisted command.

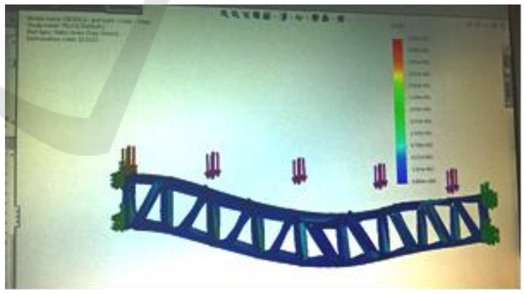
As mentioned before, while being components of modular structures in lightweight framed constructions, the LGS profiles are submitted to various loads (snow, wind, vibration, shearing / compression / bending forces) and, consequently the state of stress and strain is induced within its material. Example of loads, stress and strains for a truss made of C420 profiles is presented in Figure 6.



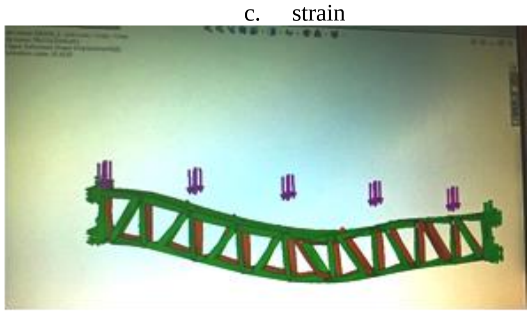
a. loading



b. von Mises stress



c. strain



d. deformed truss

Figure 6: Modelling and simulation of stress and strain.

Improving the LGS profile’s material mechanic characteristics, so as to have higher tensile strength and, when necessary, higher hardness, has been considered of benefit for the complex process of building metallic steel framed constructions. As profile thickness is of low vaules (usually, about 1.0 ÷ 3.0 mm) and, moreover, the material’s ductility should be maintained whithin reasonable values (to avoid fragile failure) the induction hardening, process has been considered and studied in this research. In a real situation when the steel framing structure is build for the metallic costruction, it is not necessary to have higher hardness or / and tensile strength values on all the profile’s length, just only on individualized parts of it, where stress and strain values are estimated to be significantly high (see the modeling and simulation in Figure 6).

The device to be used for induction hardening of the LGS C420 profile, has been designed so that to enable (Iliescu, 2018) the following:

- adequate fixture of profile (without fixturing deformation and minimising thermal deformation);
- motion of the induction coil along the profile’s longitudinal axis – with variable speed;
- rotation of the profile around its longitudinal axis, IF necessary for the thermal process optimisation;
- real time command and control of motions and process parameters values.

All the above features of the device enable the optimisation of the induction hardening process and, consequently, required values of the thermal process output variables (tensile strength, R_m, and hardness, HV) to be obtained.

Images of this customized device design for LGS profile induction hardening are shown in Figure 7. The induction hardening process, experiments carried out in order to determine, by statistical methods (design of experiments and multivariable regression), the optimal process parameters values, are presented in Figure 8.

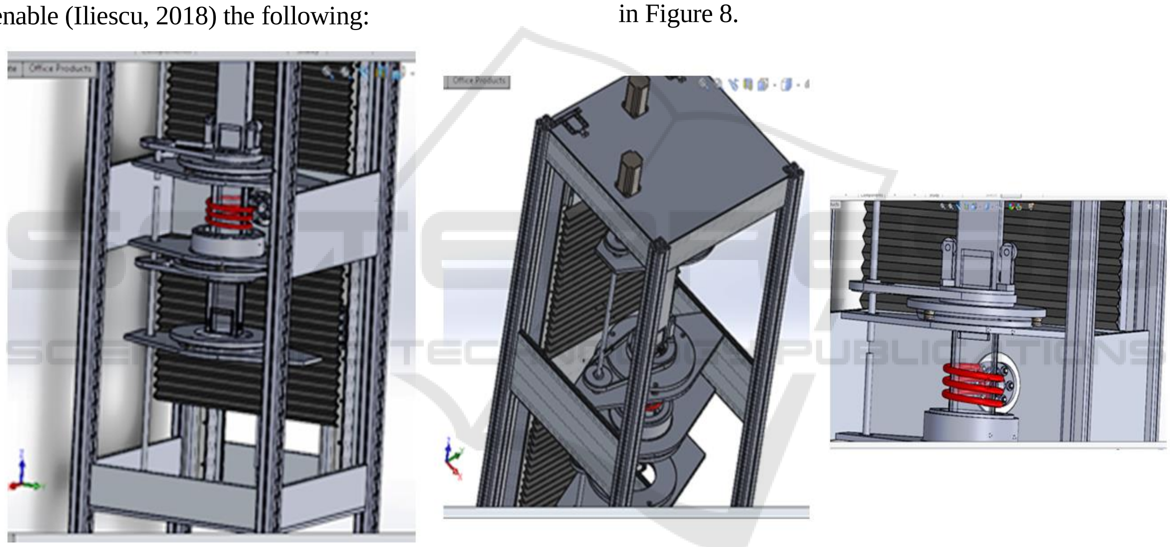


Figure 7: Device for induction hardening of the LGS profiles.

Figure 8: Experiments on induction hardening of the LGS profile’s material.

The complete manufacturing process of LGS profiles, as previously mentioned involves the cold plastic deformation process and the induction hardening process. An intelligent equipment, that enables integrated and customized building of the metallic construction is Pinnacle LGS.

Assisted by the Vertex software, the complete design and, further on, the manufacturing of LGS profiles are done, as shown in Figure 9:

- architecture;
- resistance of the steel framed construction;
- optimisation of utilities' (electricity, sanitary, thermal) paths;
- roll forming manufacturing of LGS profiles, according to all the optimisations previously set;
- estimation of all the material and components consumptions;
- estimation of time for erection of construction;
- estimation of costs: overall and categories.

Figure 9: Intelligent manufacturing system.

4 MANAGEMENT

In the current market economy, the products and services will develop in accordance with the client's ordering, therefore these will be individualized. In this context, the approaches of open innovation and product intelligence, as well as product memory, are of outstanding importance (Roblek et all, 2016).

In the LGS production processes, we are talking about smart manufacturing and smart factories. Production processes will be intelligent, flexible and dynamic and machines as well as the equipment will have the ability to improve productions processes through self-optimization and autonomous decision making (Roblek et all, 2016).

Thus, production processes are optimized in the framework of the Lean systems, resource planning is optimized in framework of ERP systems, and decisions are taken in accordance with the customer's requirements anticipation (Customer Relationship Management CRM) (Nahmias, 2009).

The Lean system is a concept which is developed on the basis on the total system approach for the efficient optimization of all production processes.

EPR is a software system that is quite sophisticated and difficult to use for identifying and planning all the necessary resources of an enterprise. The main purpose of this system is to coordinate all the production and product delivery activities.

Cross-functional decision making is a software solution that allows businesses to collect data about specific customers and all the decisions are taken at each level within the organization.

The four systems integration in any production process is called smart manufacturing (see Figure 10). The smart manufacturing system includes cyber-physical systems, the Internet of things, cloud computing, and cognitive computing. The smart manufacturing system will create what is called a smart factory. Within the modular structure of a smart factory, cybernetic systems monitor the physical processes, create virtual copies in a physical world, and decentralized decisions are made. The Internet of Things (IoT) and cybernetic systems communicate and cooperate with people in real time through the Internet services, providing added value.

Smart manufacturing combines various intelligent technologies: nanotechnology, 3D printers, mobile networks and brain research, making possible things that in the past seemed incredible. Now everyone has access to technology, and if anyone has ideas, can create inexpensive and fast products, in this mode the business model of each industry will be changed.

In the framework of smart production processes, each company can individualize its products according to the needs of each customer in a maximum efficiency context.

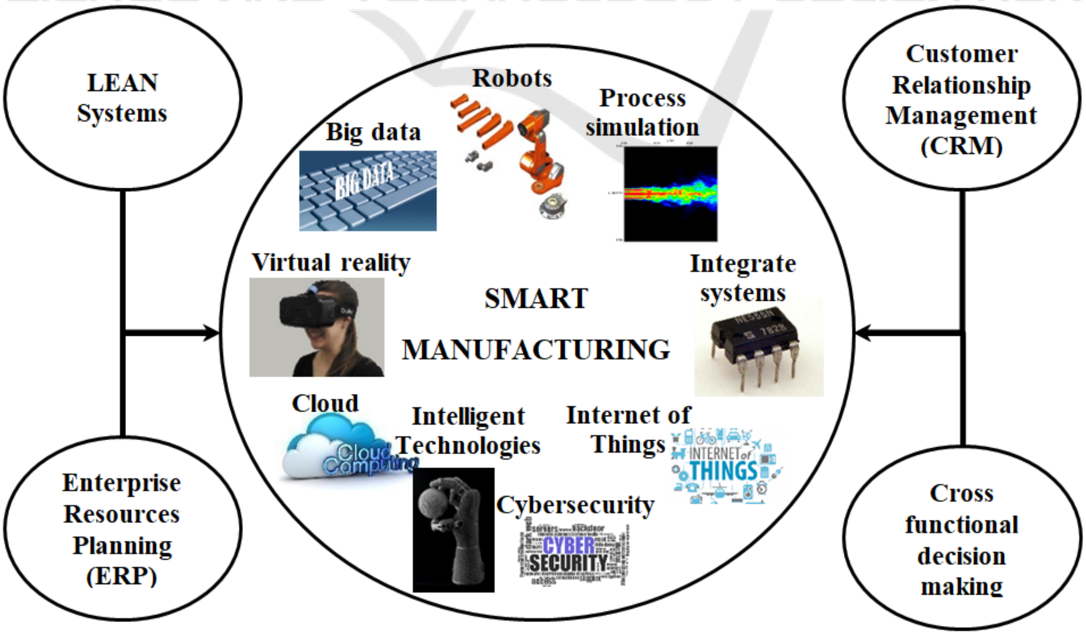


Figure 10: Smart manufacturing concept.

5 CONCLUSIONS

As nowadays focus is on friendly environmental constructions and technologies, steel framed constructions have been and extended lately, so that, an interesting and promising market is available. Lightweight steel framed constructions have as basic element the light gauge steel (LGS) profile, usually of C, or U type cross section.

The basic manufacturing process for LGS profiles is that of cold plastic deformation mainly from strip coil, in successive stages. Improving the LGS profile's material mechanic characteristics, so as to have higher tensile strength and, when necessary, higher hardness, has been considered of benefit for the complex process of building metallic steel framed constructions. The induction hardening, process has been considered and studied in this research.

An intelligent equipment, that enables the integrated and customized building of the metallic construction is Pinnacle LGS. The presentation of the manufacturing process of LGS profiles in the context of using appropriate software and intelligent equipment in conjunction with the smart manufacturing concept, has highlighted the efficiency of the production process, and pointed to the customer's satisfaction.

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