Technical, constructive and economical feasibility to turn off-grid an existing building

Sara Dorregaray-Oyaregui[1], César Martín-Gómez[1], Ignacio Hernando Gil[3], Mónica Aguado[2]

[1] Universidad de Navarra, Department of Construction, Building Services and Structures, Campus Universitario, Pamplona, Spain.
[2] Grid Integration Department Director, Spanish National Renewable Energy Center (CENER) Sarriguren, Spain
[3] ESTIA Institute of Technology, 97, allée Théodore Monod, Technopole Izarbel, Bidart, France

ABSTRACT: Existing educational buildings built with old normatives suffer a lack of technology, even though they are the frame of reference for our future society's architects(/builders). These buildings, usually promoted by the public sector, don't have significant economic investment, even if they are going to affect our children's world perception. The object construction of this study is a building from 1978. It has an educational use located at the Pamplona campus of the Universidad de Navarra. The building is part of the Living Lab of the Campus, where technologies, solutions and strategies can be proved It is a protected building by the "Documentation and Conservation of buildings, sites, and neighborhoods of the Modern Movement" (Do. Co,Mo.Mo.), so all actions that can affect its aesthetic aspects need to be justified because of the value of the building.
The methodology presented concerns the development of a replicable technical, constructive, and economical feasibility model to reach an off-grid disconnection of an existing building. The steps followed for this study are classified in seven main steps. This proposal aims to define a replicable solution that is going to be applied to other buildings of campus Universidad de Navarra in Pamplona. Even that the first solution is going to be limited by the aesthetic aspect, the final objective is to develop a Plug & Play solution following the methodology, answering the energetical deficiency and complexity of existing constructions.

KEYWORDS: off-grid; plug&play; existing; building; efficiency; saving; refurbishment; integration; renewable; replicable

1. INTRODUCTION

Buildings are responsible for 40% of the total energy consumption, according to the United Nations Environmental Program (UN Environment 2019). Thus, the concern around energy usage in buildings has been under focus; fossil fuels still being the world´s most used energy source, alternatives to their consumption are among the primary policies in consideration.
Buildings need to be refurbished, and not for aesthetical or economic reasons. It is just part of their normal life cycle. This necessity is explained in the document of the "renovation wave," where they argue that 85% of the building stock has been built before 2001. Furthermore, 85-95% of the existing building will still be in use in 2050. A proposal of the Climate Target Plan 2030 has been the reduction of greenhouse gas emissions in the European Union by 55% at least by 2030 (European Commission 2020).

> Energy efficiency is essential for action, with the building sector as one of the areas where efforts must be ramped up.

This demonstrates and measures the contributions of refurbishing our buildings. Energy technical saving shows that there can be around 30-60% in various Member States. The saving on energy consumption and the reductions of CO_2 (?) (Mata, Kalagasidis, and Johnsson 2018).

The public sector, in particular educational institutions, needs to step up and be a referent. In this context, it is important to remember that this type of building influences students directly through its interior and exterior layout, and could foster the creation of an atmosphere conductive to learning, as well as an awareness of what we need to do . (Le et al. 2018). This is already possible at new buildings, since they have the technology of control, actual building services and elevated enclosure requirements. However, historical buildings used by many education institutions would require an energy efficiency evaluation, as well as effectiveness and sustainability refurbishment solutions (Balocco and Colaianni 2018). 17% of the nonresidential buildings in the EU, are educational constructions under public control. They have high impact, public visibility, and can show a best-practice example (Österreicher 2018).
The main problem of a successful building retrofit is the complexity of the whole process. As Ma et al.(Ma et al. 2012) explains, it is not just about money. There are some key elements that have significant impact on building retrofits, including policies and regulations, client resources and expectations, retrofit technologies, building specific information, human factors and other uncertainty factors.

2. OBJECTIVES

The Universidad de Navarra's 2025 Strategy aims to contribute to the attainment of the challenges posed by society through its work researcher, professor and assistant, and in collaboration with other actors and institutions. Sustainable development and care for people and the environment are the point of reference for the orientation of its projects. Thus, sustainability in its triple dimension -environmental, economic and social- becomes the transversal purpose of the entire Strategy 2025 of the Universidad de Navarra and the projects to which it gives rise will be aligned with the Sustainable Development Goals. (Navarra n.d.)
This study is focused on the School of Architecture at Universidad de Navarra from Pamplona, a city in the north of Spain where the climate regarding the Döppen Geigger classification is considered Cfb (warm temperature, fully humid and warm summer), has an average of 27 ºC (80,6 ºF) of maximum and 2 ºC (35,6 ºF) of minimum. Built atop a tufa -a variety of limestone- plateau, with an average solar radiation of 1.000-1.300 kW/m2 and main northern wind of 5-10 m/s. The building of 1978 is located near a small river, in the south part, down the hill, of Pamplona (Fig.1). The building orientation is NNE-SSW and is surrounded by trees of high elevation with a car park at the West side. (Fig.2)
Following the Living Lab project on the Campus, this building will become the seed for diverse actions, showroom of solutions and technologies that are going to be replicated in other buildings of the Universidad de Navarra.

Fig.1,2. Left image of Pamplona and the Campus Universidad de Navarra. Right, image of School of Architecture.

Even though the building is 44 years old, it maintains its contemporary character (Fig.3, Fig.4).. The construction follows a perimetral brick enclosure with external concrete pillars that support the metallic roof. The section shows the complexity of the building (Fig.5). The internal surface distribution is homogeneous with a big and open central space. In total it has 9.486 m^2 (102106,5 ft^2) distributed in four floors. All the complete information of the building characteristics can be found at XL book of Tárrago and Cidoncha (Tárrago and Cidoncha 2020). Other relevant and conditioning aspect of the building is that it is catalogued at the Do.Co.Mo.Mo. It means that actions related to the aesthetic aspect that affect the image have to be limited and will need to be justified.


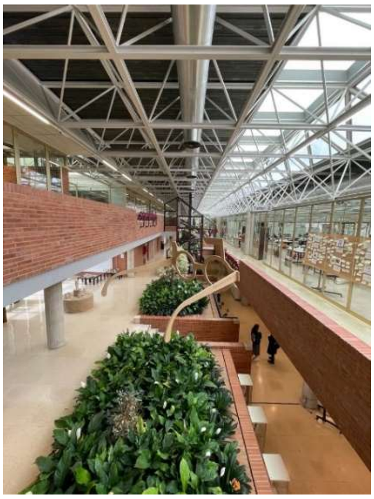

Fig 3, 4. Image of the exterior and interior of the School of Architecture at Universidad de Navarra.

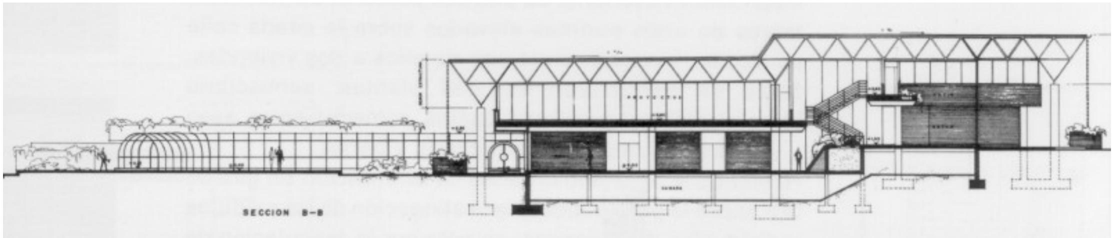

Fig 5. Section of the School of Architecture at Universidad de Navarra.

The final objective is to create and design a replicable Plug & Play solution for existing campus buildings at the Universidad de Navarra. The School of Architecture is going to be the pilot project to study and incorporate different solutions replicable in other buildings and thus becoming off-grid constructions.

3. METHODOLOGY DEVELOPMENT

To create a replicable solution, it is necessary to develop a methodology that defines the best technical and economical solution for building grid disconnection.

1. Energetical analysis. It can be gathered from the data of the electrical and thermal consumption, from an evaluation of heat losses and from a digital simulation. Thus, construction and building services are analyzed and evaluated from different levels of precision.
2. Reduction of energy requirements. It’s the reduction of the effort that needs to be done to maintain certain conditions in the interior space. Adjusting the operating mode of the building and users into a more energy-efficient one, as well as following technical recommendations of referential institutions, affects positively into energy needs of the construction. The reductions can be seen in electrical and thermal consumption and in interior space requirements.
3. Space distribution for current and future needs. A correct space distribution adapted to the use of the building, can be perceived when minimum energy is required. This minimum is going to be quantified by comparing the effort required to maintain a comfortable range in other building spaces.
4. Renewable energy resources. Study compatible and more efficient energy sources depending on the characteristics of the building and its surrounding space. Production and accumulation, commercial solutions, and disruptive technologies.
5. Match requirement and production. Calculations of demand and production to determine storage needs of thermal and/or electricity energy.

6. Control development. Optimization of energy control system of the building, with a correct control of energy use and needs.
7. Integration of plug and play solution. Creation of a replicable element, with its relative parametrizations that can "off-grid"- existing buildings. Technology implementation with capacities to develop more.

4. CASE STUDY

The replication of the developed methodology in a timeline can be seen in the following image (Fig.6). Starting from an energy audit, followed by energy reduction actions, a study of renewable energies, planning of spatial distributions and the development of control and a plug & play solution. As a result, if the methodology is correct, by 2025 the School of Architecture will be off-grid. Thus, the followed steps are going to be implemented at the Campus Universidad de Navarra by 2030.

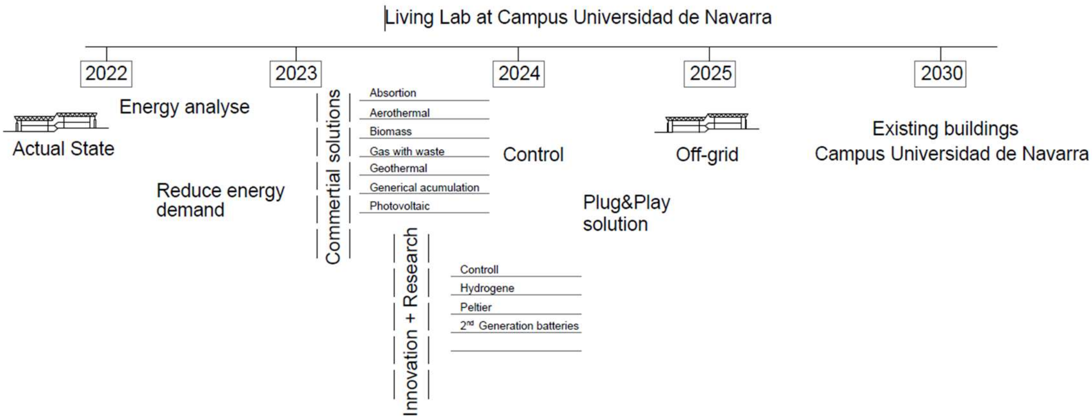

Fig.6. Process of the working scheme of this proposal at the School of Architecture at Universidad de Navarra.

4.1. Energy consumption

The first step is the energy audit of the building. The process concerns the construction and building services of the School of Architecture. The electrical consumption (lights, computers, devices and HVAC system) during 2021 has an average of 60 kW, the maximum being 195,76 kW and the minimum 8,52 kW. Figure 7 shows the energy needs during 2021. Adjacent to it, the gas consumption is detailed at figure 8, needed to boilers.

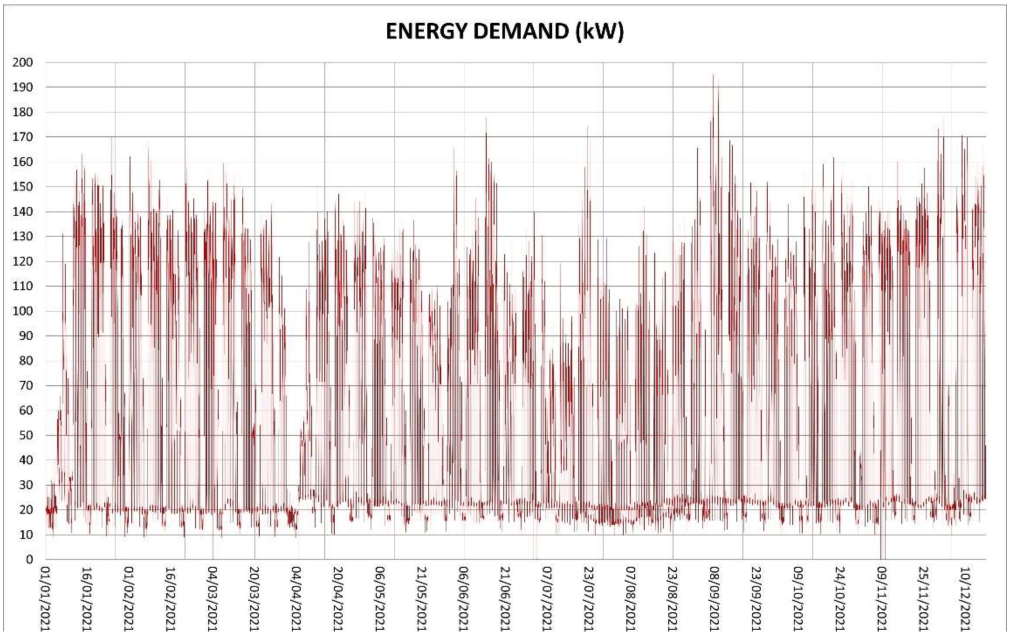

Fig.7. Electrical consumption during 2021 at School of Architecture. Hourly energy consumption during 2021.

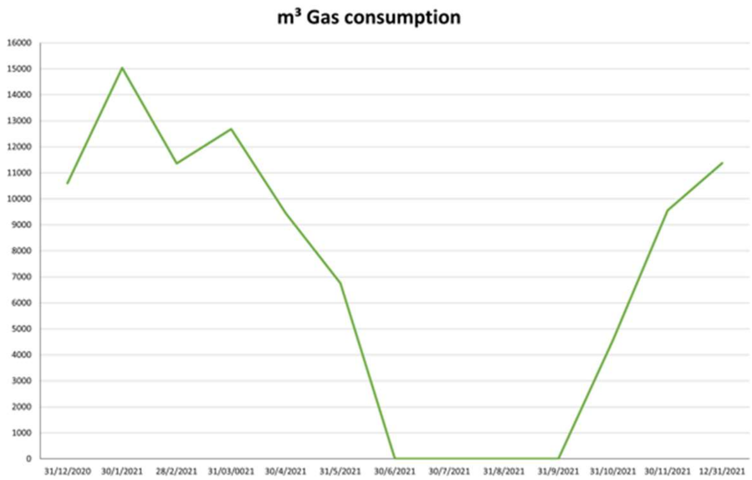

Fig. 8. Gas consumption during 2021 at School of Architecture. Monthly gas consumption during 2021.

There is a particular highlight found during the energy audit, the schedule of HVAC machines and temperatures; during the heating period, the air handling unit injected air into the ducts at 60ºC (140ºF), which is a unnecessary (if the system works correctly) and risky action due to burns and flames. Some findings, such as faulty machinery, uninsulated and broken ducts were found as well. More details of HVAC system can be found at the publication “El aire acondicionado como factor de diseño en la arquitectura española: Energía materializada” pag.316-321 (Martín-Gómez 2014),

, In conclusion, we could observe and demonstrate the high energy loss due to the inefficient properties of the building’s enclosure (lack of insulation, thermal bridges and ancient windows). This result can be extrapolated to other buildings that also have those deficiencies. Furthermore a lack of adequate use of building services, such as poor condition of ducts and machines (Fig.9) are contributing to this consumption data, forcing the need to overheat the spaces to attain a correct temperature at the building. The system management is the same in the whole campus, so the findings can be applied to other buildings.

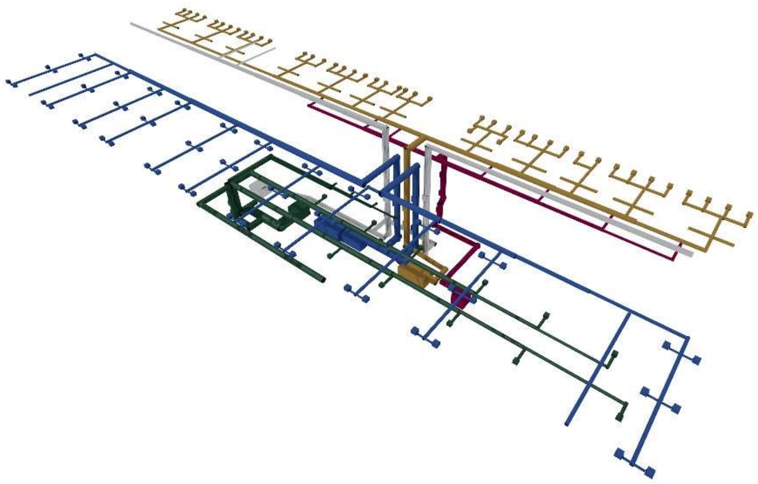

Fig. 9. HVAC duct distribution at the School of Architecture. Orange offices, blue workshop, pink classroom and green laboratory.

With demand response actions, for example, adjusting working hours on the schedule, the temperature of heated water, heating temperature, lighting, and conscious actions, it is possible to reduce energy consumption. In this case, the building reached a 23% of electric energy consumption decrease compared to the same year period , 2022-2021, achieved with an investment of zero €; Constructive elements haven't been modified. These actions are based in ASHRAE and the Código Técnico de la Edificación, CTE, (Spanish Construction Technical Code). The conscious actions are: The revision of the use of lighting, implantation of free-cooling, detection of refuge zones, and natural and cross-ventilation to avoid stratification.

The following constructive elements have been evaluated: Lights, walls, windows, and roof.
Lights will be changed by LEDs control with presence detectors in representative zones of the building. The budget is 25.000€ . The walls could be improved with blown insulation, not modifying the aesthetic part, and with an approximate cost of 50.000€. Windows can be replaced with ones recommended by the CTE and with a new type of glass but maintaining the original aspect, and an estimated cost of 600.000€. The roof can be prepared to have Photovoltaic systems and absorb NOx, after reaching a better thermal property, which would be the most expensive renovation at an approximate price point of 1.500.000€.
These solutions are commercial ones, viable, and their results could be quantified and compared with the ones of the energy audit. The possibility of comparing the results can allow the investigation and development of possible combinations. This control is essential and relevant to knowing if a solution is more or less viable before implementing it to other educational buildings of the Campus of Universidad de Navarra.
It is detected that the space distribution is not the optimal one too. Studies explain how a proper space occupation can make users more efficient and consume less energy (Zuazua-Ros et al. 2016). At the School of Architecture, the areas more exposed to sub-optimal interior conditions are those that have the longest period of occupation. It is recommended that offices be distributed on the ground floor and punctual activities on the 3rd floor.

4.2. Renewable energies

Regarding Pamplona's natural resources, (water, sun, and wind), the School of Architecture can generate between 500-800 MWh with photovoltaic panels and 11,2 W/m^2 with wind turbines. Information have been obtained from different budgets required, thus can be extrapolated to the rest of the Campus. The objective of this first approach is to have an array of scalable solutions in one building, the Living Lab. The current market and technology offer a wide range of solutions. Table 1 shows a comparative analysis of each of them from a technical, constructive, and economic point of view.

-Technical feasibility: technological level of development of the solution.

-Constructive feasibility: installation of the system and its problems or barriers.

-Economic feasibility: Comparison of the final cost of the installations. Usually related to the return period.

	Technical feasibility			Constructive feasibility			Economic feasibility			Price
	1	2	3	1	2	3	1	2	3	
Absorption			√		√		√			Not available
Aerothermal			√			√			√	300.000€
Biomass			√			√			√	Not available
Gas production with waste		√				√		√		60.000€
Geothermal			√			√		√		Not available
Hydro energy			√		√			√		Not available
Photovoltaic			√			√			√	40.000€
Peltier		√			√		√			Not available
Solar thermal			√			√			√	110.000€
Wind			√	√				√		160.000€

Table 1. Table of evaluated solutions of production of energy. 1 not feasible, 2 low feasible, and 3 high feasible.

As it can be seen, the best solutions in our case are photovoltaic, aerothermal, and biomass. Of course, not being viable solution for this building doesn't mean they aren't for others. The following lines show some of the incompatible solutions for this case study:

-Production of gas through organic waste: in this case, there is a low quantity of dust (?) production to be affordable.

-Generation with wind energy is discarded due to the airport's proximity, which limits the allowed height of elements.

-Solar thermal production: elevated weight for the existing roof.

Regarding storage, the market offers less product diversity, as can be seen in Table 2. The evaluation criteria of it is the same as in Table 1.

	Technical feasibility			Constructive feasibility			Economic feasibility			Price
	1	2	3	1	2	3	1	2	3	
Generical accumulation			√			√		√		Not available
Hydrogen		√		√			√			Not available
Thermal accumulation			√			√		√		900.000€
2nd generation batteries		√				√		√		40.000

Table 2. Table of evaluated solutions of storage of energy. 1 not feasible, 2 low feasible and 3 high feasible.

Conclusion of Table 2 is the low economic feasibility of energy storage. The most feasible options are the thermal accumulation and generic storage. The School of Architecture has a big surrounding area and building services allocation that makes it possible to insert a wide range of accumulators, from a buried tank to a series of batteries.

Control and energy require-production is not developed because the study is still in a theoretical phase. In any case, the charge cycle will be deeply analyzed to improve energy production maxims, and for that a connection with a weather database is going to be needed. Thus intelligently (?) the energy requires aren't going to be affected thanks to a good control system.

4.3. PLUG & PLAY

Last phase of the methodology is the integration and development of a Plug & Play solution. This technologycal result can be extrapolate to the rest of the campus thanks to the spaces that surrounds the buildings. This solution isn't going to affect the buildings aesthetic.
Knowing that compatible solutions of energy productions for the School of Architecture are photovoltaic, biomass and aerothermal the next hypotheses is proposed: Installations of 400kWp of photovoltaic panels to feed building requirements, with the surplus being stored. Photovoltaic panels are going to fulfill the electrical needs of the building during its academic period, and during summer are capable of generating a surplus.
Main energy storage will be done with interseasonal thermal accumulation. This is going to be materialized with a tank of 10.000 m2 that is going to pre-heat the water with the electrical surplus. Of course, it will maintain the energy until the heating period.
As a last point, even the feasibility study shows that hydrogen is not the first feasible solution: it is going to be part of the solution. This technology can give a constant and adjustable energy source thanks to its capability of be stored for long periods of time.
The following image show the concept of installing the three technologies around the School of Architecture at Universidad de Navarra. (Fig. 10) Photovoltaic panels at the parking and on the roof of the building, interseasonal thermal accumulation on the back side next to the chiller machines room, and finally the hydrogen in the left back side as an annex to the School of Architecture.

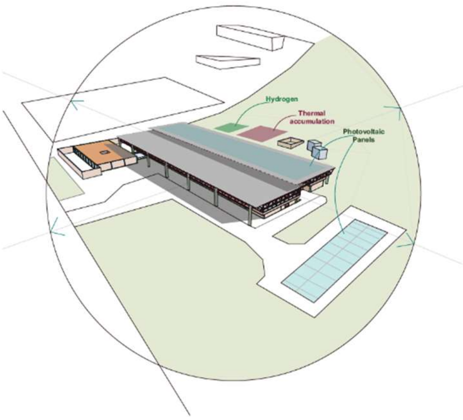

Fig.10: Draft of technology implantation at the School of Architecture of Universidad de Navarra.

These three technologies can complement each other without conflict in this theoretical hypothesis. Even if energy require-production and control are not developed, the idea allows the opportunity to adjust if needed.

5. CONCLUSIONS

In this paper, we present a methodology developed to analyse the viability to turn a building off-grid. Implemented actions respect the aesthetic aspect of this building but it is not a condition in the case of other buildings, where other implementations can be possible,. In general, existing buildings are complex and there are hundreds of variables that have a significant influence in the behavior of them. A real evaluation of the actual state gives an idea of quickly affordable solutions, especially knowing that the decarbonization process is going to be slow.

A correct space and interior distribution of buildings allows a reduction of demand. So, it is recommended that the distribution of the building of the School of Architecture be changed due to the existing one not being the optimal one, and even being detrimental for its users' health. Thus, a distribution involved from the design point of the building will have better results of comfort and energy consumption (Zuazua-Ros et al. 2016)

One key point of the methodology is the development of a control and energy management system, that is going to allow the modification and adjustment of the developed solution.

We conclude that the best solution is the combination of photovoltaic panels with thermal interseasonal accumulation and hydrogen. The idea of the industrialized solution of green energy generator and accumulation can be interesting for society. If this production is managed with an efficient control, the processes can be optimized without affecting the user's comfort.

The working group of researchers and campus managers considers the implementation of plug&play solution next to buildings. Universidad de Navarra's campus offers free spaces that is going to helps into use new technology implantation. If the results of the School of Architecture are favorable, into 2030 the work is going to be developed.

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