D1.2

Specification sheets for 3 prototypes

875629

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Abbreviation	Description
BAPV	Building Attached Photovoltaics
BIPV	Building-integrated photovoltaics
DTS	Distribution temperature sensors
DSO	Distribution system operators
EDF	Electricity of France
EE	Energy Efficiency
HC	Hard Carbon
NVPF	Na3V2(PO4)2F3
nZEB	Near Zero Energy Building (nZEB)
RES	Renewable energy sources
PV	Photovoltaic

1. Executive Summary

After identifying the requirements of the end-users in task 1.1, three specification sheets were established, fulfilling three different applications and business scenarios. These sheets were adapted to the needs of the Electricity of France (EDF), Gestamp, and Goldline in agreement with on-going regulation and industry standards of the battery industry (i.e., Batteries Directive 2006/66/EC, directive 2012/493/EU, directive (2009/125/EC). Specification sheets for three sodium-ion cells (NIBs) prototypes permit and certify the development of battery packages that will be tested, verified, and implemented in three different business scenarios. In general, after meeting with end-users, the applications requested could be achieved by 3 prototypes rather than 6. Hence, we report in this document 3 prototypes. The scope of the project has not changed. The objectives and the overall approach are completely accomplished with 3 prototypes.

2. Introduction

Batteries as electrochemical accumulators play a vital role in renewable energy systems, both on the small automotive scale and the large stationary. Working with naturally abundant materials found on the planet, such as sodium provides an economic and a cost-effective battery possibility. In the Naima project, the sodium technology for battery packs was selected since it displays interesting environmental and financial assets. The higher availability of sodium and its lower cost in this section are emphasized since they are the core criteria that permit NIB technology's penetration into the market in a successful manner.

2.1. Sodium-ion cells solution based on cost

One of the critical reasons SIBs are emerging as a promising novel technology is due to commercial advantages, as displayed in Figure 1. Sodium metal extracted from sodium salt by various electrolysis techniques has lower unit value (US$/ton) and higher production numbers (ton) than lithium. The latter's production reached its most senior figures in 2012 with $6.34*10^3$ tons with a price of 4400 US$/ton. In contrast, sodium salt reached its maximum output in 2013 with $273*10^6$ tons and a price value of 46 US$/ton, as reported by "The United States Geological Survey" [1]. The cost drop of lithium was due to a Chilean fertilizer producer that entered the lithium carbonate market in 1997, that cut down prices by about 50%[2]. A general observation of the product's price and the total production quantity shows remarkable advantages of using sodium. One can say that the production of sodium is a thousand times higher and a thousand times cheaper than lithium.

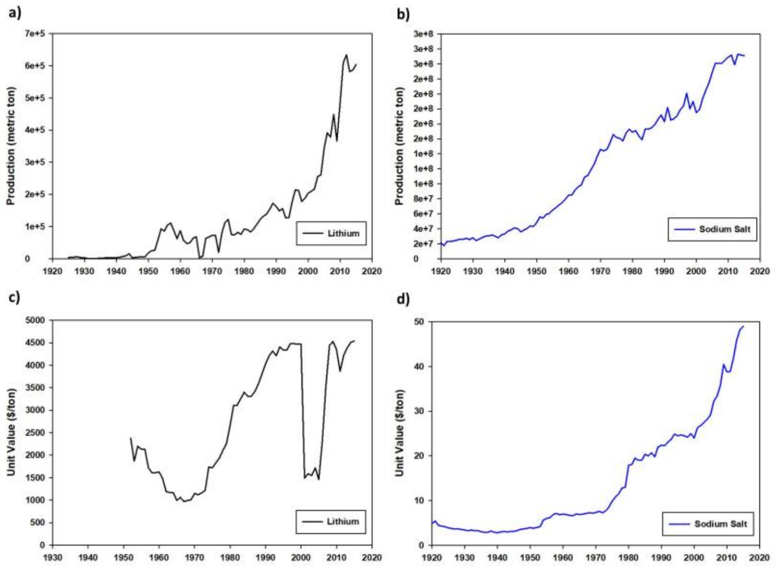

Figure 1. Lithium vs. Sodium a) production of lithium, b) production of sodium, c) unit value of lithium, and d) unit value of sodium [1].

2.2. Sodium-ion cells solution based on natural abundance

Another factor governing the success of NIBs is that the elemental abundance, which is by far more profuse than lithium. In the earth's crust, sodium abundance is 3%, whereas lithium is 0.0025%. Meanwhile, in seawater, sodium is the second most abundant element (30%), whereas lithium abundance is close to 0%. Thus, along with the previously mentioned economic advantages, sodium shows a natural richness and an elemental availability far higher than lithium. Moreover, sodium is considered one of the most abundant elements on earth with an abundance of 23600 ppm, whereas lithium's abundance is 20 ppm [3]. Besides, lithium is unevenly distributed in the earth's crust (mainly

South America). All the previously discussed matters enthused many research groups to focus on using more abundant and cheaper materials in battery synthesis, namely sodium-based materials.

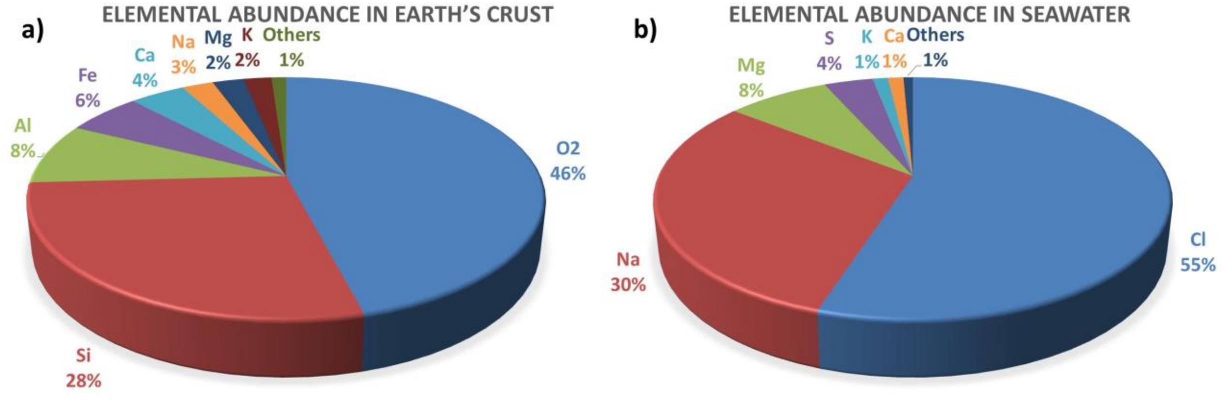

Figure 2. The elemental abundance of various elements (especially sodium and lithium) in a) the earth's crust and b) seawater.

In this report, specification sheets of three prototypes to be applied in real business scenarios are discussed.

3. Prototype 1 for Renewable generation (EDF)

The European Union targets a 20% share of energy to be obtained by renewable sources in 2020, while it aims to be the world's first continent to harness energy in a sustainable and renewable manner in 2050, as reported in the COM-19 "European Green Deal"[4]. The growth in Renewable energy sources (RES) fulfils a sustainable future, and accelerates the sharing of energy, facilitating renewable generation. The smart-grid application includes a versatile number of technologies with alternating characteristics accomplishing an increased renewable energy generation. The Electricity of France (EDF) in the NAIMA project could acquire state of the art energy storage systems that could prove valuable for grid applications.

Answering to grid applications and renewable generation requirements demanded by the EDF, and in coherence with the criteria proposed in this electrical company, a high-power cell design was introduced in the previous deliverable (D1.1). The grid functionalities permit harnessing additional renewable energy resources (RES) more safely and require an increase of the peak demand, an increase of the level of variable renewable energy, and a reduction of the level of renewable energy production. Hence, a high-power sodium-ion cell labelled as "Prototype 1" based on polyanionic family-based cathode materials can permit elevated charging current during elevated production periods and can deliver high discharge during peak demand.

Table 1: Specification sheet for Prototype 1 package (Left) and cell (Right) for renewable generation scenario for EDF.

Sodium-ion package specifications
1st Prototype for Renewable Generation (EDF)

Technical data	NVPF High Power Design 1 (Pack)
Nominal discharge capacity (Ah)	6 Ah
Nominal battery voltage (V)	48 V
Nominal Capacity (Wh)	260 Wh
Useable Capacity (Wh)	200 Wh
Cell Energy density	120 Wh/kg – 300 Wh/L
Cell Power density	3kW/kg
Peak pulse discharge power (1s) (kW)	15 kW
Peak pulse discharge power (10s) (kW)	11 kW
Peak regen pulse power (5s) (kW)	11 kW
Operating and storage temperature	-10° to 60°C
Cycle lifetime	6000
Calendar life	10-15 years
Self-discharge (1st day)	5%
Self-discharge (1 month)	2%
Maximum system weight (kg)	4.5
Maximum system volume (L)	2.5

Sodium-ion cell specifications
1st Prototype for Renewable Generation (EDF)

Technical data	NVPF High Power Design 1 (Cell)
Nominal discharge capacity (Ah)	2 Ah
Nominal battery voltage (V)	3.7 V
Cell Energy density	120 Wh/kg – 300 Wh/L
Cell Power density	3kW/kg
Maximum Charging Voltage (V)	4.25 V
Minimum Discharging Voltage (V)	2.0 V
Initial IR (AC 2kHz)	25 mΩ
Weight of the cell (g)	55 g
Charging Protocol: 1. Standard Charge 2. Fast Charge	1 A, (CC), 4.25 V for 10mins (CV) 10 A, (CC), 4.25 V for 10mins (CV)
Charging Time: 1. Standard Charge 2. Fast Charge	120 minutes 5 minutes
Discharging Protocol: 1. Standard Charge 2. Fast Charge	1 A, 2 V cut-off (CC) 35 A, 2 V cut-off (CC)

The technology behind Prototype 1 is realized on cells having a $Na_3V_2(PO_4)_2F_3$ (NVPF) cathode materials coupled with hard carbon-based (HC) anode materials. Hence, forming an energy pack that fits the needs for a high-power package for grid applications and other versatile energy applications for EDF. As discussed in the previous deliverable (D1.1), as PV smoothing demand, a favourable economic scenario based on battery modules where the Power/Energy ratio does not exceed a value of 2.5 was suggested. Prototype 1 pack module attains a 48 V nominal battery voltage with a usable capacity of 200 Wh, permitting a versatile configuration granting several types of services for EDF. Overall, this module attains an acceptable energy density (120 Wh/kg – 300 Wh/L) and a high-power density of 3 kW/kg providing an ideal module designed to sustain an average charge/discharge power of 500 W during peak demand and high energy production peak with a discharge rate 5 seconds for charging and 10 seconds for discharging.

The module will be tested in real conditions, considering the operating temperature. Such modules are usually integrated close to energy production systems located typically in temperature-controlled containers. The temperature amplitude is expected to vary between -10 °C during cold weather and does not exceed 60 °C during high module solicitation and warm weather conditions. A service life comprised between 10 to 15 years is expected to be an economically attractive condition. The typical need for a micro-grid application in terms of cycling rate is estimated to complete two cycles per day. Therefore, minimal cycle life can be expected to 6000 cycles, and 11 000 cycles are required for 15 years of use. Self-discharge should be ideally of the same order than Li-ion. For example, a loss of around 5% is expected within the first day, and 2% per month afterward. Strong self-discharge such as supercapacitors adds operational costs and render such devices uncompetitive. Finally, the Prototype 1 battery weighs 4.5 kg and occupies and overall volume of 2.5 L.

4. Prototype 2 Industry (GESTAMP)

Industrial revolutions are shaping the economy of the European Union, and since the industry is regularly evolving, the energy supply supporting its safe and stable functionality is vital. The challenges that industrial expansions present are immense. Namely, the work and operating conditions of these bodies are considered harsh. Consequently, safely supplying power for these highly digitalized and automated industries is a mandatory criterion. Another critical factor shaping the success of smart factories relies on the ability of an energy management system to power a sophisticated, reliable network of integrated sensors at a competitive cost.

The prototype proposed to Gestamp takes into consideration the specific application they requested. These batteries are for a particular purpose that features saving data in case of a power outage, hence the implementation of these batteries as integrated energy storage systems for industrial robots. Several robots require these batteries, and the prototype package aims to replace the lithium-ion battery packages already functioning in these robots. The fundamental requirement for this application is a package of 10.8 V with around 17 Ah capacity. In Naima, Prototype 2 proposed is a battery compiling a polyanionic cathode material and a hard-carbon anode material which provides another high-power package capable of meeting the demands of a potential power outage. This package consists of 27 cells distributed as 3 cells per series and 9 cells in parallel. The power outage is not expected to occur daily; hence, daily charging and discharging of these packages seem redundant. The packages should attain a low self-discharge over time, another point met by this prototype. Furthermore, long cycle life is compulsory, another criterion gratified by prototype 2. The cell's specification is identical to that of prototype 1 since the technology serves to provide high power. Nevertheless, the package assembly and the module proposed for this specific application is different.

The specification sheet provided in table 2 further explains some criteria of Prototype 2. Namely, an 11.2 V battery module of 180 Wh is envisioned as a versatile and flexible power solution to validate the application for the robot's data saving. This device is fabricated to hand a maximum peak discharge of 3 kW in five seconds while attains a peak recharge rate of 2 kW in ten seconds. Such a device is required to handle maximal peak charge power of 500 W and addresses power demand up to 500 W in discharge. The operating conditions in Gestamp are unusually mild and should fluctuate within a 10°C–60°C range. However, this module can operate in worse conditions where it has a -10°C–60°C operating range. The financial attraction and competition are due to the service life, which is expected to reach at least 8000 cycles, which represent a highly competitive cost that is five times lower per cycle than lithium-ion (0.01 €/kW/cycle rather than 0.05 €/kW/cycle) based packages. The overall price of the system is more than three times cheaper than lithium-ion packages (103 € rather than 334 €).

Prototype 1 is also proposed for industrial applications; However, with minor modifications. Thus, both prototypes 1 and 2 are intended for Gestamp. Prototype 1 is a high-power package made up of 39 cells distributed as 13 cells per series and 3 in parallel. This configuration adds to the overall robustness of these energy storage systems since it is a highly stable system that proved enough power to surge the industrial needs in various applications while maintaining its safety when operated in unfavourable environments. The technology serving these purposes is identical to prototype 1. However, they are configurated to serve higher stability for specific industrial usage. The polyanionic cathodes, coupled with the hard carbon, deliver a high-power cell design that sustains high charging currents for power equipment. The considerably low cost of these materials provides financial assurance to the industries while preserving their energetic integrity.

Table 2: Battery specification sheets for Prototypes 1 & 2 packages and Cells for Industrial application for GESTAMP.

Sodium-ion cell specifications
1st Prototype for Industry (GESTAMP)

Technical data	NVPF High Power Design 1 (Pack)
Nominal discharge capacity (Ah)	6 Ah
Nominal battery voltage (V)	48 V
Nominal Capacity (Wh)	260 Wh
Useable Capacity (Wh)	200 Wh
Cell Energy density	120 Wh/kg – 300 Wh/L
Cell Power density	3kW/kg
Peak discharge rate (5s) (kW)	3.5 kW
Peak recharge rate (10s) (kW)	1 kW
Operating and storage temperature	-10° to 60°C
Cycle lifetime	8000
Self-discharge (1st day)	5%
Self-discharge (1 month)	2%
Maximum system weight (kg)	4.5
Maximum system volume (L)	2.5

Sodium-ion cell specifications
2nd Prototype for Industry (GESTAMP)

Technical data	NVPF High Power Design 2 (Pack)
Nominal discharge capacity (Ah)	18 Ah
Nominal battery voltage (V)	11.2 V
Nominal Capacity (Wh)	200 Wh
Useable Capacity (Wh)	180 Wh
Cell Energy density	120 Wh/kg – 300 Wh/L
Cell Power density	3kW/kg
Peak discharge rate (5s) (kW)	3 kW
Peak recharge rate (10s) (kW)	2 kW
Operating and storage temperature	-10° to 60°C
Cycle lifetime	8000
Self-discharge (1st day)	5%
Self-discharge (1 month)	2%
Maximum system weight (kg)	1.9
Maximum system volume (L)	1

Sodium-ion cell specifications
2nd Prototype for Industry (GESTAMP)

Technical data	NVPF High Power Design 1&2 (Cell)
Nominal discharge capacity (Ah)	2 Ah
Nominal battery voltage (V)	3.7 V
Nominal Capacity (Wh)	6.6 Wh
Cell Energy density	120 Wh/kg – 300 Wh/L
Cell Power density	3kW/kg
Maximum Charging Voltage (V)	4.25 V
Minimum Discharging Voltage (V)	2.0 V
Initial IR (AC 2kHz)	25 mΩ
Weight of the cell (g)	55 g
Charging Protocol: 1. Standard Charge 2. Fast Charge	1 A, (CC), 4.25 V for 10mins (CV) 10 A, (CC), 4.25 V for 10mins (CV)
Charging Time: 1. Standard Charge 2. Fast Charge	120 minutes 5 minutes
Discharging Protocol: 1. Standard Charge 2. Fast Charge	1 A, 2 V cut-off (CC) 35 A, 2 V cut-off (CC)

Validating the industrial capabilities of prototype 2, GESTAMP will implement these high-power packages in their industrial applications. The monitoring of these systems, as previously discussed in the deliverable (D1.1), will be carried out by this company. Energy management systems, based on big data, allows real-time monitoring of energy consumption needs, enabling the connection of the plant infrastructure to a solution in the cloud. This automated information technology solution offers a diagnosis of electricity and gas consumption hence providing a detailed visualization of the utilization of specific points for their analysis. The high-power packages based on the prototype 2 module will decrease the contracted power on the plants due to the minimization of power peaks and reducing the energy costs.

The second package specification sheet provided in table 2 further explains some criteria of the altered Prototype 1. Namely, a 48 V battery module of 200 Wh is envisioned as a versatile and flexible power solution to validate the application for industry. This device is fabricated to hand a maximum peak discharge of 3.5 kW in five seconds while attains a peak recharge rate of 1 kW in ten seconds. Such a device is required to handle maximal peak charge power of 500 W and addresses power demand up to 500 W in discharge. The operating conditions in Gestamp are unusually mild and should fluctuate within a 10°C–60°C range. However, this module can operate in worse conditions where it has a -10°C–60°C operating range. The financial attraction and competition are due to the service life, which is expected to reach at least 8000 cycles, which represent a highly competitive cost that is five times lower per cycle than lithium-ion (0.01 €/kW/cycle rather than 0.05 €/kW/cycle) based packages. The overall price of the system is more than three times cheaper than lithium-ion packages (103 € rather than 334).

5. Prototype 3 Private-Households (GOLDLINE)

In 2017, statistics regarding energy consumption in households in the European Union was presented by Eurostat. In that year, "households represented 27% of the overall energy consumption in the European Union" [5]. Natural gas and electrical sources cover almost 60% of the final residential energy consumption. Renewable energy sources account for only 18% of the overall energy consumption. Most of the buildings built before the year 2000 have a severe lack of energy and insufficient integration of RES in the building. However, the development of RES is of prime importance to meet the EU targets. In the emerging climatic context, the Near Zero Energy Building (nZEB) concept becomes a keystone to meet Europe's 2030 Energy Efficiency (EE) targets [6].

Renewable energy resources in private households and buildings mainly harness energy from naturally sustainable sources (i.e., solar and wind energy). As reported in deliverable 1.1, solar photovoltaic (PV) energy in buildings, two technologies cover the whole market:

1- Building Attached Photovoltaics (BAPV): a photovoltaic module used as a part of the building's envelope. Namely as facades, rooftops, skylights, and many others.
2- Building-integrated photovoltaics (BIPV): the entire building integrates electricity generation while serving as a functional building unit.

Likewise, wind energy harnessed by mini turbines installed in buildings aims to reach 204 GW in 2020 to cover 16.5% of the European Union's electricity demand in 2020 [7]. The previous RES requires a perfect integration with an energy storage unit to guarantee stable energy and power supply in any house. The economic competition could be secured with a low-cost energy storage system integrated within the smart grid of households. This application requires the following specifications:

- The building is connected to the network via its own distribution temperature sensors (DTS) with an installed power transformer of 630 kVA. The agreed power with distribution system operators (DSO) is 405 kW. Though, in practice, 120 kW is the peak consumption of this building.

- The installed photovoltaics on the roof is a 48 kW PV design.
- The EV charging is still not even close to the installed capacity. Currently, they have 6 charging stations, each of them is connected to 22 kW power. However, they rarely use more than 19 kW in total as a peak.
- No issues with the suggested package and cell specification., no mass/volume issues, they can use the package indoors or outdoors. Thus, they have flexible solutions. Also, energy and power density seem to be appropriate.
- Safety regulations should be compliant with that of European regulations. Thus, in general, there are no safety issues.
- The building is an advanced operation unit. It does not include a battery as ESS. In terms of application, the distribution system operator might be a problem. This situation is to be addressed in the future.

Table 3: Battery specification sheet for Prototype 3 package (Left) and cell (Right) for private households' application for GOLDLINE.

Sodium-ion cell specifications

3rd Prototype for private households (Goldline)

Technical data	NVPF High Energy Design (Pack)
Nominal battery voltage (V)	600-700V
Useful Capacity (kWh)	400 kWh
Peak discharge rate (5s) (kW)	5
Peak recharge rate (10s) (kW)	7
Operating and storage temperature	0°C – 60°C
Maximum operating voltage (V)	~690 V
Minimum operating voltage (V)	~656 V
Minimum energy efficiency	92%
Maximum allowable self-discharge rate	95%
Maximum system weight (kg)	<7000 kg
Maximum system volume (m^3)	< 3 m^3
Self-discharge (1st day)	5%
Self-discharge (1 month)	2%

Sodium-ion cell specifications

3rd Prototype for private households (Goldline)

Technical data	NVPF High Energy Design (Cell)
Nominal discharge capacity (Ah)	2.9 Ah
Nominal battery voltage (V)	3.5 V
Nominal Capacity (Wh)	7.7 Wh
Cell Energy density	200 Wh/kg – 420 Wh/L
Cell Power density	2 kW/kg
Maximum Charging Voltage (V)	4.4 V
Minimum Discharging Voltage (V)	1.2 V
Initial IR (AC 2kHz)	45 mΩ
Weight of the cell (g)	60 g
Charging Protocol: 1. Standard Charge 2. Fast Charge	 0.58 A, (CC), 4.4 V for 10mins (CV) 14.5 A, (CC), 4.4 V for 10mins (CV)
Charging Time: 1. Standard Charge 2. Fast Charge	 300 minutes 12 minutes
Discharging Protocol: 1. Standard Charge 2. Fast Charge	 0.58 A, 1.2 V cut-off (CC) 14.5 A, 2 V cut-off (CC)

The energy storage unit proposed in the NAIMA project includes a prototype package 3 that enables a specific solution for households based on the lamellar oxide families as this family focuses on low-cost materials that can cycle thousands of cycles, a feature that has been seldom demonstrated so far. The technology behind this prototype includes manganese doped cathode materials, which are considered inexpensive and greener than conventional cathode materials utilized in commercial lithium-ion batteries. The energetic properties of these cathode materials are considerably higher than polyanionic based cathode materials, but they lack behind in their power capabilities.

GOLDLINE will provide a demo site for the prototype 3 module addressed to the private household battery system. The site will consist of an office building in Sofia (Bulgaria). The building has a rooftop with PV panels and storage units, where separate transformers and independent interconnections within the distribution grid are also available. The specification of the battery pack is depicted in Table 3. For household application at building scale, a pack of 400 kWh is required with a nominal voltage of 600 V. The peak discharge rate of these batteries is 5 kW in five seconds and has a peak recharge rate of 7 kW in ten seconds. The minimum energy efficiency of this package is 82%, while a maximum self-discharge rate of 95% is allowed. The operating and storage temperature ranges between 0°C and 60°C. Self-discharge is expected to be in a range of 5% within the first day, and 2% per month afterward. Nevertheless, the overall weight of the package is lower than 7 tons. The complexity of the importance and the configuration that would accommodate around 50,000 cells of 21700 format is problematic. Thus, household ESS can be emulated with a more practical and representative module composed of 500 cells that provides a 1 kWh capacity and has a nominal voltage of 48 V.

6. Conclusions

After obtaining the requirements and identifying the needs from end-users for implementing packages in specific applications, **three specification sheets for three prototypes** are presented in this document.

Prototype 1 is a 48 V package with high power-density cells are proposed for grid applications for EDF. **Prototype 2** is an 11 V package also with high power-density cells are recommended for implementation in robots for Gestamp. Also, a modified prototype 1 is offered to Gestamp for other industrial applications. **Prototype 3** is a 600-700 V package with high energy-density cells that are provided for private household applications for Goldline. The specification sheets include information that explains in what manner each cell meets the end-users demand. Finally, decisions for these sheets were made after an exchange with end-users ensuring that the prototypes proposed to meet their requirements.

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