ENergy aware BIM Cloud Platform in a COst-effective Building REnovation Context

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D6.2 Final Validation Procedure

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EXECUTIVE SUMMARY

This deliverable describes the criteria that will be used in the ENCORE project to evaluate and assess its performance towards achieving its objectives and impact. The measures identified will play an important role in effective monitoring of the scientific and technical achievements and provide key indicators that quantify the expected impact of the project in the construction sector. The measures have been derived using an industry accepted methodology for defining measurement programmes and have been grouped in categories regarding the pilot measures, the research and development aspects and the technology aspects.

INDEX OF CONTENTS

INDEX OF FIGURES

INDEX OF TABLES

1. INTRODUCTION

1.1 OVERVIEW

This deliverable provides a set of evaluation criteria, and respective data collection approaches, which the ENCORE partners will use to measure and assess the performance of the project in achieving the objectives outlined in the Description of Actions (DoA). The measures identified using the Goal-Question-Metrics (GQM) approach, developed by Basili et al. (1994)[1], will be also used towards an effective project management. This approach is recognised to be a valuable for helping project and development managers define and align measurement programmes to project goals.

In order to succeed the adequate evaluation of the ENCORE solution, the project partners had to conclude to a balanced set of measures that will support the assessment of work within the project, while not diverting substantial resources to measurement collection and data analysis. The measures suggested below, for the ENCORE early prototype, were selected with the desire to have simple metrics whenever possible so that the achievements of the project are more easily conveyed to the broadest audience.

As the metrics selected below reflect to the early prototype of the solution, they may be adjusted as the project proceeds and further experience is being gathered while developing and testing the services.

1.2 DOCUMENT STRUCTURE

The document is divided into the following sections:

- Section 2: presents the methodology suggested for the evaluation of the ENCORE solution.
- Section 3: describes the measures that will be used to evaluate the ENCORE pilot.
- Section 4: presents the research and development measures.
- Section 5: describes the measures for evaluation the technology capabilities of the ENCORE solution.
- Section 6: presents a summary of this document.

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[1] *Basili, V., Caldiera, G., & Rombach, H.D. (1994). The Goal Question Metric Approach.*

2. ASSESSMENT CRITERIA METHODOLOGY

The ENCORE project has used the approach of goal-oriented measurement as a basis for developing the monitoring and assessment criteria specified in this document. In particular, the project has adapted the Goal, Question, Metric (GQM) method developed by Basili et at. (1994)[2], refined during the 1990s. GQM has become a *de facto* standard for the definition of measurement frameworks. One of the reasons for its success is that it is adaptable for use by many different organisations and in many environments, as confirmed by the large number of companies that have used it (e.g. Philips, Siemens, NASA, Hewlett Packard, Motorola).

The GQM method is used to define measurement in such a way that:

- Resulting metrics are tailored to the project and its goals.
- Resulting measurement data play a constructive and instructive role in the project.
- Metrics and their interpretation reflect the values and the viewpoints of the different groups affected (e.g. developers, users, researchers).

As illustrated in the Figure 1 below, GQM begins by identifying measurement goals (conceptual level) that support (are aligned with the) overall project goals. The consortium then poses questions (operational level) to further clarify and refine the goals, as well as to capture the variation of understanding of the goals that exists among the partners. The consortium then identifies metrics that will provide answers to the questions (quantitative level).
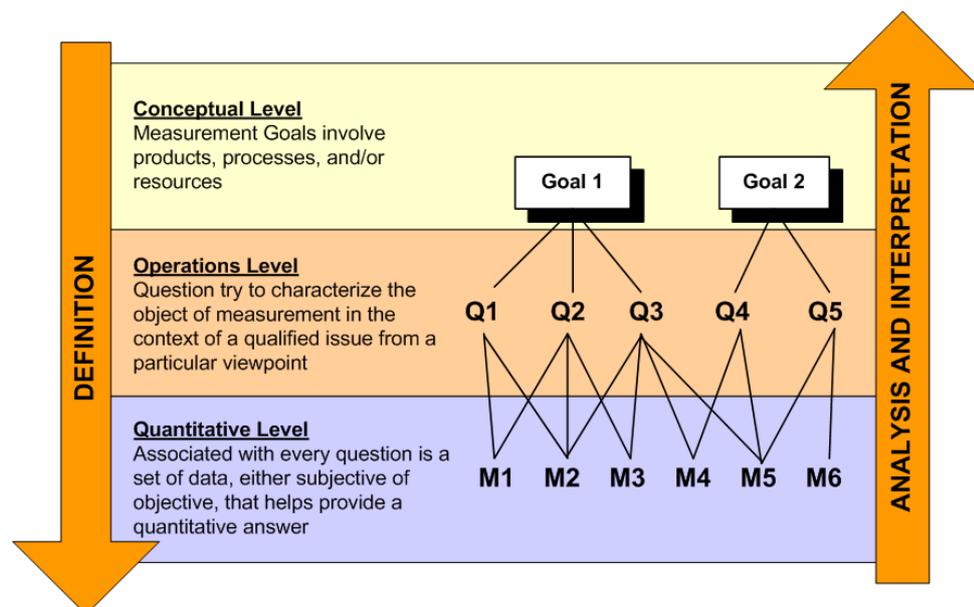

Figure 1 – Overview of GQM methodology

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[2] *Basili, V., Caldiera, G., & Rombach, H.D. (1994). The Goal Question Metric Approach.*

What distinguishes GQM from other measurement paradigms is the hierarchical tree structure used to maintain the relationships amongst goals, questions, and metrics.

2.1 CRITERIA-REFINEMENT PROCESS

GQM uses a six-step process. The first three steps are about using the overarching project goals and desired impact on the construction sector, to drive the identification of the right metrics, whereas the last three steps are about gathering the measurement data and making effective use of the measurement results to drive decision making and improvements. The adaptation of Basili's six-step GQM process being utilised by the ENCORE project is as follows:

1. Identify a set of construction sector and project goals

2. Generate questions that define those goals in a quantifiable way

3. Specify the measures needed to be collected to answer those questions and track process and project conformance to the goals

4. Develop mechanisms for data collection

5. Collect, validate, and analyse the data to provide feedback for corrective action

6. Analyse the data periodically to assess conformance to the goals and to make recommendations for future improvements

The ENCORE project with the energy aware BIM cloud platform in the building renovation-context aims to:

1. boost the renovation industry and increase the share of renovation stock

2. provide affordable BIM tools to cover the whole renovation lifecycle

3. facilitate information exchange among related stakeholders

4. and consequently, to reduce renovation costs

Coupled with the higher-level goals of the H2020 ICT work programme, the project also seeks to address:

- the renovation working time, by allowing a reduction compared to current practices, in the area of renovation design process and the energy analysis and comfort simulation.

- the creation of best practice examples for the construction retrofitting sector, benefiting the related stakeholders

- the industrial exploitation of renovation businesses amongst the construction and renovation companies

For each of these objectives there are specific tasks to be undertaken and results in the form of deliverables identified. The focus of this deliverable is to provide specific measures that allow the partners and the European Commission to assess the degree to which these objectives have been achieved.

2.2 CRITERIA-REFINEMENT EXAMPLE

The ENCORE partners have applied the GQM methodology to establish a set of measures that will be used to evaluate and assess the performance of the project from several different perspectives. The project goals were then taken and considered at an operational level in terms of how the goal could be achieved, and which implications each goal has on the outcomes of each work package. These were stated in the form of questions that should be answered in the affirmative if the higher-level goal is being achieved.

Once the partners had a set of questions to consider at the operational level, then the challenge was to identify quantitative measures that could be used to verify that each individual question could be satisfied. As the GQM methodology anticipates, some quantitative measures identified addressed more than one question at the operational level. Furthermore, in some cases the operational level questions had multiple dimensions to consider, which in turn required the use of more than one quantitative measure.

An example of how GQM was applied to establish the evaluation criteria and measures shown in Figure 2 for the technological goals of the ENCORE solution.
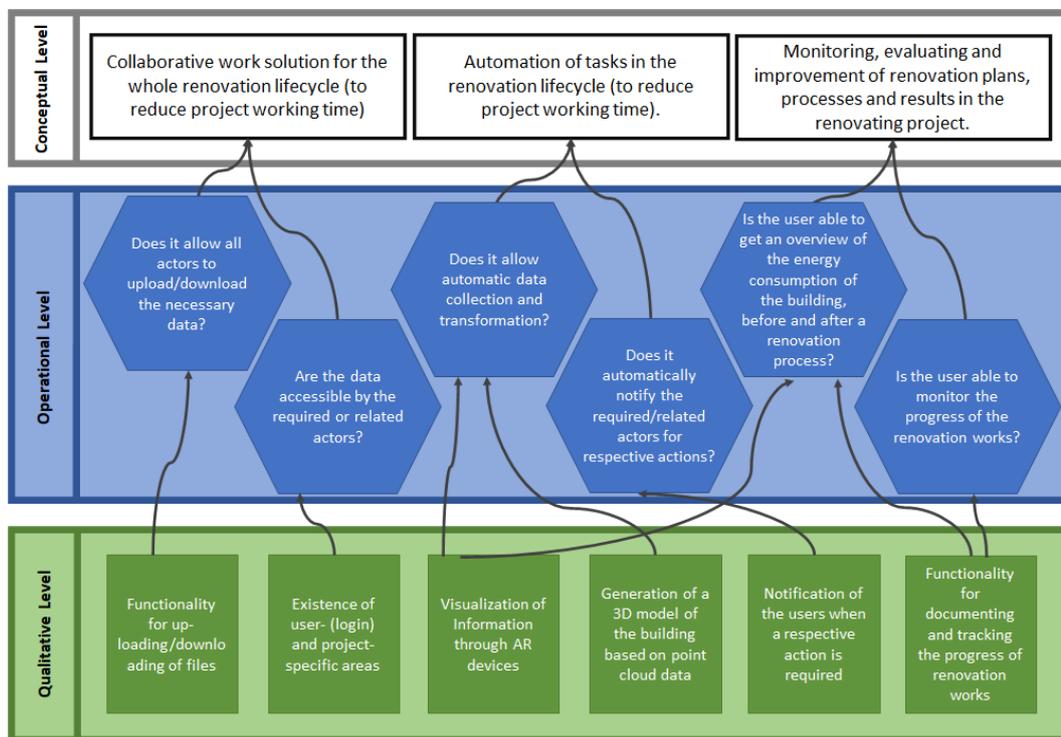
Figure 2 – Applying GQM to determine ENCORE evaluation criteria

Figure 2 illustrates the application of the GQM methodology for only part of the overarching goals that the project partners expect to achieve through the research and development within the project. The evaluation of the other overarching goals, as well as technology objectives and market impact objectives has also been addressed through many more measures established for the project using GQM. These measures for evaluating the performance of the project in meeting each of the ENCORE project goals

are specified in this deliverable both in terms of the rationale for including the metric and the measurement process that will be utilised. A table with the overall goals for the ENCORE solution, taking into account for the final validation procedure are presenting in Table 4: Goals identified for the ENCORE final validation procedure in the APPENDIX.

The ENCORE partners recognise that the success achieved by a project of the size and complexity of ENCORE will be multifaceted as the project itself starts with several broad primary objectives which require multiple measures in order to sufficiently evaluate whether the project has attained the expected levels of achievement.

Using the GQM method the project has identified a set of quantifiable measures that will enable the project partners and the European Commission to evaluate and monitor the progress the partners make towards achieving the goals of the project. As the measures sometimes relate to multiple goals, they have been grouped into four categories:

- **Pilot Validation** – measures that indicate the degree to which ENCORE services have an effect on improving and supporting building renovation companies and individual stakeholders that seek to exploit opportunities for renovation cost and project-time reduction.

- **Research and Development** – measures that identify the degree to which project innovations are meeting the current and future requirements of construction sector and in particular, are delivering advances beyond the current state-of-the-art in evaluating renovation projects.

- **Technology Adoption Readiness**– measures that monitor key elements that will determine the attractiveness and rate at which ENCORE services can be expected to be adopted by the construction sector.

The measures for assessment and monitoring in each of the above categories are described in detail in Sections 3 through 5.

2.3 TYPES OF MEASURES

2.3.1 Comparative measures

Some of the evaluation criteria the project has specified need to be considered with regard to the relative improvements that were achieved when compared with already existing renovation process solutions. This provides a reliable measurement approach, as the normal variations that might occur between different solutions are largely removed, and one can more easily represent the impact of the ENCORE research and development results as an expression of relative improvement, which is more easily understood by other organisations in the construction sector.

Procedures for calculating comparative measures specified for the ENCORE project evaluations are structured in one of two different ways:

- **Before and after** – the measures are calculated by undertaking a specific task related to building renovation using current technologies and practices, followed by the same task being undertaken using the ENCORE services.

- **Side-by-side** – the measures are calculated by carrying out tasks related to building renovation in parallel where one individual, or group, uses current technologies and practices, while another, uses the ENCORE services to carry out the task.

The "before and after" approach for comparative measures typically requires fewer resources to carry out the measurement procedure. There is also potentially less variability in the resulting values due to differences in skills and experiences of personnel compared to the two individuals, or groups, used for the "side-by-side" approach. However, in some cases, the side-by-side approach is preferred when evaluating a new capability or carrying out a task that is not already familiar, or in place within the Pilot Case partner, as it can provide a more scientific measurement using a control group and experiment group to quantify benefits and advances provided by ENCORE.

2.3.2 Qualitative measures

There are improvements provided by the ENCORE services that are difficult or complex to quantify, or that have a significant subjective element affected by the construction sector, the capabilities, or previous experience of the individuals carrying out the evaluations. These are, nonetheless, as important as more quantified measures as they represent important aspects, such as ease of use and other elements that can have a substantial impact on whether the ENCORE services can be broadly adopted in the construction sector. These improvements are quantified using satisfaction measures which are more often calculated using a questionnaire format where questions are asked about certain capabilities and experiences associated with use of the ENCORE services.

A common element of all the satisfaction measures specified for the ENCORE evaluations is the use of a four-point Likert[3] scale that also employs the "forced choice" method so that evaluators are required to take a position either favourable or unfavourable towards the improvement or advancement provided by the ENCORE services. The typical scale used for the questionnaire responses are as follows:

- Fully achieved
- Largely achieved
- Partially achieved
- Not achieved

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[3] A Likert scale is a psychometric scale commonly involved in research that employs questionnaires and is the most widely used approach to scaling responses in survey research. Respondents specify their level of agreement or disagreement on a symmetric agree-disagree scale for a series of statements.

Depending on the question and evaluation topic the precise wording of the scale is adjusted for the specified satisfaction measure. For example, "agree" might be used instead of "achieved" while still maintaining the principle of the four-point Likert scale.

While a five-point scale is perhaps more precise in terms of data acquisition, (i.e. a neutral position is a valid data point), the intended use of the project evaluation measures will be in motivating the take-up of the ENCORE services in the construction domain and identifying any opportunities for future improvements during the exploitation phase. Therefore, a higher importance is placed on capturing positive and negative positions of the pilot evaluators than on reflecting the nuances of responses to individual questions as neutral positions, neither motivate take-up nor contribute to further improvements of the ENCORE services.

2.4   MEASUREMENT COLLECTION

Several techniques will be used for collecting measurement data during the assessments. The selection of the appropriate techniques will vary according to the particular measure, the nature of the pilot case involved, and the level of collaboration needed in case a consensus view is targeted. The techniques that may be used include the following:

- **Verbal Protocol**: this is a think aloud protocol where users vocalise thoughts, goals, perceptions, opinions, feelings and talk about their actions whilst performing tasks[4]. This method allows the evaluator to understand how the participant approaches a particular task and their reasoning when interacting with the interface. Any differences between the expectations on how to conduct a specific task and the actual sequence of the steps required in order to complete that task will be highlighted using this technique.

- **Focus group**: usually involves 4-8 participants and 1-2 moderators. The interaction between participants can lead to insights about certain issues which would not usually emerge from the use of individual interviews[5]. Participants could either be the same type of user, or different stakeholders from an organisation. The moderator has specific goals and objectives for a focus group session and usually guides the direction of the discussion.

- **Questionnaire**: a custom-made questionnaire is used to assess perceptions-based experience when using the project services, and to compare previous experience or expectations with those involving the use of the project to determine users' personal preference. For the reasons noted in Section 2.3.2, these questionnaires will use a four-point Likert scale.

- **Observation**: this method involves observing the actions or performance of the renovation crew in conjunction with the project services and innovations to

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[4] See Bainbridge,L.,Verbalprotocolanalysis,inEvaluationofhumanwork,J.R.WilsonandE.N. Corlett, Editors. 1990, Taylor and Francis: London.

[5] See Morgan,D.L.andR.A.Kreuger,Whentousefocusgroupsandwhy,inSuccessfulFocus Groups, D.L. Morgan, Editor. 1993, Sage: London, UK.

measure the changes (i.e. improvements) that result from the new capabilities made possible by the project services. Different types of comparative observation measures can be collected as discussed in Section 2.3.1.

- ▪ **Interviews**: interviews can be organised to be structured, semi-structured or unstructured[6]. They allow participants to express their thoughts in their own words and can provide insight into their thought processes. Structured interviews consist of a specific, defined set of questions. Open-ended unstructured interviews allow more of a conversation between the evaluator and the participant. This would allow the interviewer to ask broader, or more detailed questions about the topics that arise during the interview and would allow the participant to provide additional information. Contextual interviews involve interviewing the user in context while they are conducting the renovation work activities.

As a framework for the above defined Observations and Interviews the Contextual Inquiry method will be used as defined in the Contextual Design methodology. Contextual inquiry is a field data collection technique used to capture detailed information about how users of a product interact with the product in their normal work environment. This information is captured by both observations of user behaviour and conversations with the user while she or he works. A key aspect of the technique is to partner with the user, letting their work and the issues they encounter guide the interview. Key takeaways from the technique are to learn what users actually do, why they do it that way, latent needs, desires, and core values

Assessment can also be performed automatically and remotely by means of scripts that capture specific events in the interaction between the ENCORE services and the pilot case partner systems and personnel. These actions may be registered in a log file that can be queried and analysed remotely. Also, the assessment could be performed manually and on-site by following the steps identified in a testing procedure.

2.5   ASSESSMENT SETTING

The ENCORE work plan has been structured to include two assessment settings; the first will be completed at the end of the second year of the project using the early prototype services. This assessment will be used by the project partners to help shape the further development of the project and will be reported in deliverable *D6.4 ENCORE Final Validation Report.* The final assessment will be carried towards the end of the project and will be more comprehensive using the full prototype services.

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[6] See 6. Fontana,A.andJ.H.Frey,TheInterview:FromStructuredQuestionstoNegitiatedText,in Handbook of Qualitative Research, K.D. Norman and Y.S. L., Editors. 2000, Sage Publications Ltd.: London, UK. p. 645-672.

3. PILOT VALIDATION MEASURES

The pilot-case-specific measures represent assessments that are relative to the current capabilities of the pilot case partner without the use of ENCORE, as compared to the capabilities, improvements, and benefits provided through the ENCORE services are applied within the specific environment of the pilot.

These measures are helpful in understanding the level of improvements achieved and, therefore, the expected impact in the construction sector ENCORE will have for organisations. In addition, they indicate the degree to which the development partners have delivered technology that addresses the needs of typical construction retrofitting companies. Most importantly they quantify the sector improvements achieved from the ENCORE services in a way that they will be relatable and easily understood by similar organisations in the construction sector.

The existing baseline measure, or performance indicator will already be known to the Pilot Case partner, and the Pilot Case-specific measure quantifies the improvement achieved when the ENCORE services are utilised.

In order to carry out a detailed analysis of the improvements and benefits of using ENCORE, it has been decided to carry out this analysis in detail in the different apps and engines that make it up.

Therefore, and taking as a reference the Use Cases Scenarios, defined in Deliverable 1.5 Pilot Cases and Use Cases Scenarios, they have been segregated into more detailed ones (see Table 1) that represent the different activities that can be carried out by the stakeholders participating in the energy refurbishment process along the building life cycle.

The measurement method and the quantitative and qualitative measures will be defined to each Detailed Use Case Scenario. These measures can be classified as: capabilities, features, economic, time and usability.

ID	DETAILED USE CASE	ENCORE Services/engines	Target end users	Pre-Design	Design	Construction	Operation
DUC01	RENOVATION PROJECT SET UP, MANAGEMENT AND KNOWLEDGE REPRESENTATION	ENCORE PORTAL, BIM VIEWER, KEES	ARCHITECT, BUILDING OWNER, CONTRACTOR	✓	✓	✓	✓
DUC02a	3D MODELLING OF EXISTING BUILDING USING DRONES	DAS, IPRS, MICROSERVICE IFC	ARCHITECT, BUILDING OWNER, CONTRACTOR	✓			
DUC02b	3D MODELLING OF EXISTING BUILDING USING MOBILES	DAS, IPRS, BREA, MICROSERVICE IFC	ARCHITECT, BUILDING OWNER, CONTRACTOR	✓			
DUC02c	3D MODELLING OF EXISTING BUILDING USING ONLINE SOURCES	BREA, MICROSERVICE IFC	ARCHITECT, BUILDING OWNER, CONTRACTOR, DWELLER, PUBLIC GOVERNMENT	✓			
DUC03	BUILDING ENERGY MODELLING FOR ENERGY ASSESSMENT	BREA, BRM	ARCHITECT, BUILDING OWNER, CONTRACTOR, DWELLER, PUBLIC GOVERNMENT	✓			
DUC04	ENERGY ASSESSMENT OF EXISTING BUILDING	BREA, BRM	ARCHITECT, BUILDING OWNER, CONTRACTOR, DWELLER, PUBLIC GOVERNMENT	✓			
DUC05	DESIGN RETROFITTING STRATEGIES	BREA, BRM	ARCHITECT, BUILDING OWNER, CONTRACTOR, DWELLER, PUBLIC GOVERNMENT		✓		
DUC06	ENERGY ASSESSMENT OF RETROFITTING STRATEGIES	BREA, BRM	ARCHITECT, BUILDING OWNER, CONTRACTOR, DWELLER, PUBLIC GOVERNMENT		✓		
DUC07a	SELECTION THE MOST OPTIMUM SOLUTIONS: PERFORMANCE COMPARISON	BREA,	ARCHITECT, ENGINEER, CONTRACTOR, DWELLER?		✓		
DUC07b	SELECTION THE MOST OPTIMUM SOLUTIONS: ON-SITE DISPLAY OF RENOVATION DESIGN AND CONSTRUCTABILITY	ODAVS	ARCHITECT, EXPERT		✓		
DUC08	PLAN THE RENOVATION WORKS	AWOPS	CONTRACTOR, DWELLER?			✓	
DUC09	MONITORING THE RENOVATION WORKS	AWOPS,	CONTRACTOR, DWELLER?			✓	
DUC10	REQUIREMENTS FOR SENSORS & CONTROLS	BMS	ENERGY SERVICES COMPANY	✓	✓	✓	✓
DUC11	REALTIME CONTROL, DATA RECORDING AND REPORTING	BMS	ENERGY SERVICES COMPANY, DWELLER?	✓	✓	✓	✓
DUC12	MONITORING OF THE CONDUCTION AFTER RENOVATION WORK	CPMS	DWELLER				✓

Table 1: Detailed Use Case Scenarios

3.1 MEASUREMENT METHOD

Justification

Usage is an important indication when determining the capabilities provided by the ENCORE platform, as the overall system should be able to get data as input, and support identifying and comparing renovation options, planning, and monitoring of the renovation actions, and get an insight in the energy efficiency and comfort benefits. Traditionally, usage has been a complicated aspect to assess in research projects, but ENCORE benefits from the pilot case partner having available building monitoring infrastructure, along with associated existing data available for carrying out actual usage evaluations.

Specification

The usage assessment measure will be based mainly on the pilot case scenario for renovation process optimisation and a comparative analysis will be carried out where the process will have been carried out without the use of the ENCORE services, and the process is then undertaken with the use of it. This evaluation measure is predicated on the prior completion of tasks within other evaluation measures, specifically: analytics selection, objective function formulation and optionally, situational event detection. The procedure for calculating the measure is the following:

1. A set of quantifiable performance measures will be established for determining the level achieved at task completion.

   In both demonstration buildings, all the enclosures have been monitored in order to study and analyse the data that the tests that will be carried out in the pilot cases. The sensors are grouped by zones. A set of data acquisition modules is located in each of those zones, the sensors are connected to that data acquisition modules and the modules are connected to each other via Ethernet cable. The existing monitoring system consists of the following types of sensors: Room temperature (indoor), Relative humidity, Surface temperature (windows, walls, internal partitions), CO_2 concentration, Water flow, Power consumption, Heat flux and U value.

   All the building's installations are equipped with measurement systems that allow managing the control and correct operation of the facilities.

2. A first iteration will involve carrying out the tasks without the use of ENCORE services or to establish a baseline already in place at the pilot case.

3. A second iteration will utilise the ENCORE services during the performance of the task and will determine in a quantified manner the improvements introduced by it. The performance measures established in 1) will be collected for comparison with the baseline.

If needed, some detailed use case scenarios will be analysed trough additional pilot tests which consider different aspects, such as the typology and size of the building or its location. This is important, in example, for 3D building modelling, or energy assessment.

The usage assessment measure would be calculated as follows and represented as a percentage value.

$$\text{Usage Assessment} = \frac{\text{Performance measures values using ENCORE}}{\text{Performance measures values without ENCORE}}$$

A common evaluation scale is not defined for the category of pilot case-specific measures, as the measures can vary substantially in impact for the construction sector even within the same pilot case. The important criterion is that the measured improvement should be recognised as important, and the improvements achieved be considered significant to others in the same, or similar, construction sectors as the respective pilot case partner.

Each of these specific measures will be collected and evaluated by the pilot case partner within the context of its retrofitting systems. The overall assessment for each measure when reported will include two components: 1) the quantified measure stated in terms of % improvement or other relative indicator; and 2) a description of the importance of the quantified measured achieved within the context of the pilot case partner and infrastructure.

3.2 QUANTITATIVE MEASURES

The detailed-use-case quantitative measures that have been for the demonstrator tests and assessments activities are shown in the following table.

Table 2: Detailed-use-case quantitative measures

Detailed Use Cases	CAPABILITIES		FEATURES		ECONOMIC		TIME		USABILITY	
	METRIC	UNIT	METRIC	UNIT	METRIC	UNIT	METRIC	UNIT	METRIC	UNIT
RENOVATION PROJECT SET UP , MANAGEMENT AND KNOWLEDGE REPRESENTATION			Integrated BIM Viewer	yes/no	Cost	€/year	Time to access renovation project data	minutes		
			Automatic Enhancement of IFCs	yes/no			Time required for management of renovation projects	minutes		
			Collaborative Project Workspace	yes/no			Automatic enhancement of IFC models with renovation project information during project duration	minutes		
			Integrated CDE	yes/no			Training time	minutes		
			Integrated Energy / Comfort Simulation	yes/no						
			Integrated Design Analysis	yes/no						
			Integrated Work Planning / Monitoring	yes/no						
			Integrated Building Operation Support	yes/no						
			BMS Dashboard	yes/no						
			Renovation Projects	yes/no						
			Support for IFC models	yes/no						
3D MODELLING OF EXISTING BUILDING (USING DRONES)	Level of Accuracy of the BIM model				Cost	€/m2	Modelling Time	minutes/m2		
							Training Time	hours		
3D MODELLING OF EXISTING BUILDING (USING MOBILES)	Level of Accuracy of the BIM model				Cost	€/m2	Modelling Time	minutes/m2		
							Training Time	hours		
3D MODELLING OF EXISTING BUILDING (USING ONLINE DATA SOURCES)	Level of Accuracy of the BIM model				Cost	€/m2	Modelling Time	minutes/m2		
							Training Time	hours		

Category	Metric	Unit			Cost/Metric	Unit	Time/Metric	Unit	Metric	Unit
BUILDING ENERGY MODELLING FOR ENERGY ASSESSMENT	Level of Accuracy of the BIM model				Cost	€/m2	Modelling Time	minutes/m2		
							Training Time	hours		
ENERGY ASSESSMENT OF EXISTING BUILDING					Cost	€/m2	Simulation Time	minutes/m2		
							Training Time	hours		
DESIGN RETROFITTING STRATEGIES	Level of Accuracy of the BIM model				Cost	€/m2	Modelling Time	minutes/m2		
							Training Time	hours		
ENERGY ASSESSMENT OF RETROFITTING STRATEGIES					Cost	€/m2	Simulation Time	minutes/m2		
							Training Time	hours		
ON-SITE DISPLAY OF RENOVATION DESIGN AND CONSTRUCTABILITY	Rate of successful technical assessment	Percentage							Usability of the expert user interface	Likert
									Usability of the virtual menu	Likert
									Accessibility of the architect user interface	Likert
PLAN THE RENOVATION WORKS	Tracking	€					Time	minutes		
MONITORING THE RENOVATION WORKS	Detected spatial conflicts	Percentage					Time Step	Overall duration / no. of progress updates		
REQUIREMENTS FOR SENSORS & CONTROLS	Accuracy levels				Sensor cost	€	Installation Time	hours		
					Installation cost	€				
					Running cost	€				
REALTIME CONTROL, DATA RECORDING AND REPORTING	Indoor comfort levels				Energy usage	€				
	User beahviour (space occupancy)				Running cost	€				
	Energy consumption									
	Energy efficiency degradation									
MONITORING OF THE CONDUCTION AFTER RENOVATION WORK	Iterations and interactions	Number					Training Time	hours		
	Level of OTE	Percentage								

3.3 QUALITATIVE MEASURES

The detailed-use-case qualitative measures that have been for the demonstrator tests and assessments activities are shown in the following table.

Table 3: Detailed-use-case qualitative measures

Detailed Use Cases	CAPABILITIES		FEATURES		USABILITY	
	METRIC	**UNIT**	**METRIC**	**UNIT**	**METRIC**	**UNIT**
RENOVATION PROJECT SET UP , MANAGEMENT AND KNOWLEDGE REPRESENTATION	Renovation project organisation efficiency	good/mediocre/bad			Usability of integrated solution	good/mediocre/bad
	Simplicity of GUI, clean design	good/mediocre/bad				
	Understanding information through data representation/visualisation	good/mediocre/bad				
3D MODELLING OF EXISTING BUILDING (USING DRONES)	Increase of automation in BIM creation					
3D MODELLING OF EXISTING BUILDING (USING MOBILES)	Increase of automation in BIM creation					
3D MODELLING OF EXISTING BUILDING (USING ONLINE DATA SOURCES)	Increase of automation in BIM creation					
BUILDING ENERGY MODELLING FOR ENERGY ASSESSMENT	Increase of automation in BIM creation					
ENERGY ASSESSMENT OF EXISTING BUILDING			Energy demand	yes/no		
			Final energy consumption	yes/no		
			Final energy consumption by source	yes/no		
DESIGN RETROFITTING STRATEGIES	Type of Retrofitting Strategies	Passive/Active/Renewable Contributions				
ENERGY ASSESSMENT OF RETROFITTING STRATEGIES			Energy demand	yes/no		
			Final energy consumption	yes/no		
			Final energy consumption by source	yes/no		
			Energy demand covered by renewable sources	yes/no		
			Renovation works cost	yes/no		
			Amortization period	yes/no		
			Renovation works time	yes/no		
			Level of intrussion	yes/no		
			Embebbed Energy	yes/no		

COMPARISON OF DESIGNED AND ACTUAL PERFORMANCE			Energy demand	yes/no	
			Final energy consumption	yes/no	
			Final energy consumption by source	yes/no	
			Energy demand covered by renewable sources	yes/no	
			Renovation works cost	yes/no	
			Amortization period	yes/no	
			Renovation works time	yes/no	
			Level of intrussion	yes/no	
			Embebbed Energy	yes/no	
PLAN THE RENOVATION WORKS	Process smoothness				
MONITORING THE RENOVATION WORKS	Clashes fixing				Update of work progress
					Visualization of work progress
REQUIREMENTS FOR SENSORS & CONTROLS	Technology type				
	User self installation				
MONITORING OF THE CONDUCTION AFTER RENOVATION WORK					Understandability
					Comprehension
					Assessment

4. RESEARCH AND DEVELOPMENT MEASURES

The measures for evaluation of research and development are intended to identify the degree to which the project is progressing towards implementing the expected technology innovations, and the extent to which the innovations will contribute to improvements for European organisations. These measures are intended to be aggregated measures utilised for determining how well the project development work is progressing towards achieving a platform suitable for exploitation and improving of project time and cost in building renovation actions. The measures centre on the requirements from the construction sector and the detailed technical requirements for service innovations that fulfil the industrial requirements and provide substantial improvements beyond the current state-of-the-art.

4.1 REQUIREMENTS COVERAGE ASSESSMENT

Justification
The ENCORE solution is driven by requirements set out in deliverable *D1.2 Requirements Analysis*. The project will track each of the requirements and address these requirements both from an architectural and development standpoint. While not all requirements may be fully within the scope/resources of the project, the percentage of Pilot Case requirements that have been satisfied provides an important measure of the applicability of the project results in solving the industrial challenges for big data application developers that are targeted by the project.

Specification
The ENCORE project will use a requirement tracking tool that lists the identified industrial requirements and mapping of requirements to specific work packages and services within the ENCORE solution. The percentage of total requirements being implemented in one or more services of the ENCORE solution will be available from the requirements tracking tool for periodic reporting. Priorities of requirements (e.g. Shall, Should, May) have also been specified by the Pilot Case project partner and will be included in the coverage reporting.

The evaluation scale for the measure will be the following:

"Shall" Requirements Implemented	Evaluation
Greater than or equal to 90%	Excellent
Between 80% and 90%	Good
Between 70% and 80%	Sufficient
Less than 70%	Insufficient

4.2   TECHNICAL REQUIREMENTS IMPLEMENTED ASSESSMENT

Justification
Technical requirements have been defined for each of the ENCORE services based on the requirements that are documented in *D1.2 Requirements Analysis*. The technical requirements measure counts the number of requirements that have been defined and allocated to services in the respective work packages and successfully developed for the early and full prototypes. The project has been tracking the requirements as it allows the partners to plan resources and to prioritise those requirements that provide the greatest value towards achieving the overall goals of the project.

Specification
The ENCORE project will use a requirement tracking tool that will list identified work package requirements and mapping of requirements to specific services within the ENCORE platform technologies. The requirements associated with each functional service will be tracked and when a service has been implemented the requirements will be reported as implemented. In some cases, requirements will span multiple services in which case all functional services will need to have been completed for a requirement to be considered fully implemented.

The evaluation scale for the measure will be the following:

"Shall" Requirements Implemented	Evaluation
Greater than or equal to 90%	Excellent
Between 80% and 90%	Good
Between 70% and 80%	Sufficient
Less than 70%	Insufficient

5.   TECHNOLOGY ADOPTION READINESS MEASURES

The ENCORE solution is intended to be exploited in a variety of scenarios ranging from using just some or all ENCORE services in targeted ways to support the automation of specific tasks, up to organising the whole renovation project based on the integrated ENCORE solution and connected external systems. Key technology capabilities developed in the research and development work packages need to be evaluated to ensure the project results will address the needs of the construction sector, meet expected levels of performance and usability, and that the results can be tailored to address a wide range of scenarios. Key aspects to be considered related to performance, degree of automation and maturity, and quality of results.

For the early prototype services these evaluation measures will of course be lower than for the full prototype services delivered in the later months of the project.

5.1   PERFORMANCE

Justification
Performance of the ENCORE services is an important indicator as to whether the project technologies are likely to be adopted by construction organisations.

Specification
The ENCORE project will use a survey instrument with user partners where their views as to the performance of the ENCORE solution is collected. The survey will include the following questions:

- ▪ The perceived time for the ENCORE solution to create a BIM model using drones and automated IPRS.

In addition, there will be an opportunity for the Pilot Partner personnel to provide comments and clarifications concerning their experiences and why they chose specific ratings in each category.

The scale for answering the questions will be the following:

- ▪ Fully agree
- ▪ Largely agree
- ▪ Partially agree
- ▪ Don't agree

The evaluation scale for the measure will be the following:

Questionnaire responses	Evaluation
All responses fully positive	Excellent
All responses positive	Good
Majority of responses positive	Sufficient
Majority of responses negative	Insufficient

5.2   MATURITY

Maturity is a subjective measure and must be taken within a specific context since the assessment is typically relative to the tools or technologies currently available to an application developer, or technologies or practices that are customarily used within an organisation to carry out similar tasks.

Specification
The ENCORE project will use a survey instrument with Pilot Case user partners where their views as to the maturity of the ENCORE platform are collected. The survey will include the following questions:

- The perceived maturity of the ENCORE solution for the development and execution of the Pilot Case specific application was acceptable.

- The perceived ability to integrate ENCORE solution within existing infrastructures and equipment was adequate.

- The perceived reliability (in terms of stable operation) of the ENCORE solution swas acceptable.

- The perceived skill levels required for using the ENCORE solution was within the capabilities of the BC organisation.

In addition, there will be an opportunity for Pilot Case partner personnel to provide comments and clarifications concerning their experiences and why they chose specific ratings in each category.

The scale for answering the questions will be the following:

- Fully agree
- Largely agree
- Partially agree
- Don't agree

The evaluation scale for the measure will be the following:

Questionnaire responses	Evaluation
All responses fully positive	Excellent
All responses positive	Good
Majority of responses positive	Sufficient
Majority of responses negative	Insufficient

6. CONCLUSIONS

The ENCORE services aim to provide effective and affordable BIM tools that cover the whole renovation life-cycle. In order to evaluate and assess the ENCORE solution, the Goal, Question, Metric (GQM) approach was chosen. This document presents the selected measurement criteria, as well as it describes how those data will be collected.

The measurements following the GQM approach, can be grouped in categories referring to measure for the validation of the pilot, research, and development measures, as well as technology measures. As the project proceeds and more experience from the developed services is being acquired, those measures may be adapted to fit the respective purposes.

This document presents the final version of validation procedure, which will be applied to assess the impact of the ENCORE engines and apps developed in the project.

7. APPENDIX I

The following table presents the measures selected to evaluate the goals identified for the early prototype of the ENCORE solution.

Table 4: Goals identified for the ENCORE final validation procedure

Conceptual Level	Comment	DUC Covered	Req. Covered	Operations Level	Qualitative Level
Collaborative work environment/solution for the whole renovation lifecycle . POINT: (Data) Communication	e.g. able to upload and share between the stakeholders their data/knowledge	DUC01, DUC7a,	EPICS(ENC-42-47), ENC-56, ENC-57, (ENC-58,) ENC-59, ENC-61, ENC-63, ENC-73, ENC-76, (ENC-82), ENC-89, (ENC-91,) ENC-92, ENC-93, ENC-95, ENC-96, ENC-98, (ENC-108,) (ENC-110,)	1. Does it allow all actors to upload/download the necessary data? 2. Are the data accessible by the required or related actors? 3. Does it allow actors to review the data or comment on them? 4. Does it allow actors to communicate directly with each other?	1. Functionality for upload/download of files 2./3. Existence of GUI elements for data visualisation 2./3. Existence of user-specific and project-specific areas 2./3. Shared access to a project for a group of users 2./3. Existence of GUI elements for data processing 3./4. Possibility to write comment on chosen data 4.Posibility to send direct messages or emails 5.Visualization of renovation options through AR/MR devices.

| Automation of tasks in the renovation lifecycle

POINT: Automation	e.g. auto-create BIM, notify users of task completion and support continuous scheduling	DUC2a, DUC2b, DUC2c, DUC3, DUC4	ENC-41, ENC-48, ENC-49, (ENC-50,) ENC-51, ENC-62, ENC-63, ENC-74, ENC-87, ENC-89, ENC-93, ENC-99, ENC-100, ENC-105, ENC-106, ENC-109	1.Does it allow automatic data collection and transformation? 2.Does it automatically notify the required/related actors for respective actions? 3.Is it possible to identify building elements automatically? 4.Does it perform a holonic management for semi-automated work planning? (5.Is it possible at any time to view, online, information on the status of the renovation tasks?)	1./3.Aquire building geometry information using drones 1./3. Acquire data using mobile devices (e.g. smartphone) 1. Generate a 3D model of the building based on point cloud data. 2. Include planners and technicians in the management and decisional process. 3.Search for building components in the IFC model 4. Dynamic service to plan a renovation process based on user input (5.Building monitoring and visualisation options using cloud facilities) (5.Renovation process visualisation options using cloud facilities) 6. Include resource analyses and verification in the processes of the work plan.

Confidentiality: Public Distribution

Monitoring, evaluating and improvement of renovation plans, processes and results in the renovating project. POINT: Management and Quality	e.g. get overview of on-going tasks, get overview of energy consumption, select preferred renovation option	DUC5, DUC6, DUC7a, DUC7b, DUC8, DUC9, DUC11, DUC12	ENC-52, ENC-53, ENC-56, ENC-57, ENC-59, ENC-60, ENC-63, ENC-65, ENC-66, ENC-77, ENC-78, ENC-80, ENC-81, ENC-84, ENC-85, ENC-86, ENC-92, (ENC-94,) ENC-103	1.Is the user able to get an overview of the energy consumption of the building before and after a renovation process? 2.Is the user able to compare the energy solution to be applied in the renovation? 3. Is the user able to monitor the progress of the renovation works?	1./(5.b)Building monitoring and visualisation options using cloud facilities 1./(5.b)Renovation process visualisation options using cloud facilities 2./(1.b)Renovation options selection through AR devices 2./(2./3.b) Existence of GUI elements for data visualisation 3. Functionality for documenting and tracking the progress of renovation works

8. APPENDIX II

The following table shows a template fulfilled to collect the pilot validation procedure and the KPIs for a Detailed Use Case.

Table 5: Pilot Validation Procedure and KPIs for Detailed Use Case ENERGY ASSESSMENT OF EXISTING BUILDING

USE CASE	Type here the NAME OF THE USE CASE
STAGE	Type here the name of LIFECYCLE STAGE
ENCORE SERVICES, APPS or ENGINES	Type here the NAME OF THE SERVICES, APPS or ENGINE
ENCORE PARTNERS INVOLVED	Type here the NAME OF THE PARTNER
TARGET END USERS	Type here the NAME OF THE TARGET OR END USER
ENCORE ASSESSMENT METHOD	Type here the NAME OF THE ASSESSMENT METHOD
TRADITIONAL METHOD	Type here the NAME OF THE TRADITIONAL ASSESSMENT METHOD

ID	KPIs	DESCRIPTION OF PLANNED METODOLOGY	TYPE	UNIT	ENCORE VALUE	TRADITIONAL METHOD	DESCRIPTION OF ACTUAL METODOLOGY
1	SIMULATION RESULTS						
1.1	Type in this column the KPIs List	Type in this column the description of the planned methodology	Type in this column QUANTITATIVE OR QUALITATIVE	kWh/m2	Type in this columna the measurement unit	Type here a traditional method when available	Type in this column the description of the methodology used for the assessment pase on the pilot case
1.2							

1.3

2 ECONOMIC

2.1

3 TIME

3.1

3.2