D4.2 Digitalization requirements and KPIs

MULTICARE

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Dissemination Level:	Public
Lead Partner:	TU Delft
Due date:	31 March 2024
Actual submission date:	31 March 2024

PUBLISHED IN THE FRAMEWORK OF

MULTICARE (Horizon Europe grant 101123467)

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REVISION AND HISTORY CHART

VERSION	DATE	EDITORS	COMMENT
V0.1	24 March 2024	Justin Schembri (TU Delft)	First draft
V0.2	25 March 2024	Azarakhsh Rafiee (TU Delft)	Review
V1.0	26 March 2024	Justin Schembri (TU Delft)	Final Version

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Executive Summary

This report outlines a methodology for assessing the effectiveness of the digital tools developed by the MultiCare Consortium. Here a set of user-centric KPIs are defined, their scope being to assess the impact, perception and overall performance of the various digital features and services included in the suite of MultiCare digital solutions.

Categorized broadly, the digital suite is composed of 1) decision support systems, 2) monitoring and 3) early warning systems and 4) urban resilience assessment tools. The tools have use-cases applicable at various architectural scales, namely, 1) component, 2) building and 3) neighborhood levels. Each digital tool augments some multi-risk, resilience-based approach to assessing urban risk to natural hazards. These tools serve as the digital implementation and distribution of the theoretical work developed in other MultiCare WPs. While by their nature digital tools have no direct physical impact on the real world, the digital suite offers stakeholders the platform by which to apply and assess the effectiveness of the physical solutions developed in MultiCare.

A subset of these KPIs aims to assess whether a digital tool has fulfilled its defined functional objective. By way of example, if a tool's function is to allow users to calculate *Resilience Readiness Levels* for an archetypical building, the KPI, *Task Completion Rate*, calculates the ratio of users who successfully complete that given task. Other KPIs may measure digital technical performance, for example the speed of processing some given algorithm. KPIs may be applied to individual functions or the overall broader package where those functions form part of.

The KPIs outlined in this report cover four domains, namely 1) **features and functionality**, 2) **user experience / user interface**, 3) **technical performance** and 4) **behavior dynamics**. The first and second domain focus on the user experience, investigating aspects such as the ease by which a user completes a specified task on a digital platform. The third domain focuses on the computational performance of the software and the final fourth domain the ability of the digital suite to change user's behavior or workflow. Baseline measurements may not always be possible, owing to the newness of the tools. However, in some cases, structured interviews and survey techniques may refer to a user's experience carrying out a task they have carried out before using other means (e.g., other existing software packages) and after the MultiCare digital tool.

This deliverable, authored by TU Delft, with the support of consortium members IES, OMRT and ARUP, delineates the methodology's scope. Rigorous review by relevant partners responsible for specific interventions ensures its appropriateness and robustness.

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GLOSSARY

ACRONYM	FULL NAME
KPI	Key Performance Indicator
WS	Work Stream
WP	Work Package
SDSS	Spatial Decision Support Systems
EWS	Early Warning System

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1. Introduction

1.1. MultiCare project

The built environment is ill-prepared for more frequent and increasingly intense climate-related extreme events. The current building stock is particularly vulnerable because it has limited or no capacity to adapt and recover from extreme events thereby leading to building failures that cause severe socio-economic losses and adversely affecting the health and wellbeing of people. Recent scientific and technological advances in the construction industry provide timely solutions for improving the resilience for specific single hazards (e.g. flood hazard or seismic hazard), but they are often not cost effective, rarely eco-friendly and nearly never address the multiple hazards present in many locations. This is hardly surprising because there is neither a clearly defined framework for quantifying the whole-life socio-economic-environmental impacts of extreme natural events nor tools for assessing the holistic climate resilience of buildings. Consequently, it is currently very challenging to develop/select optimal solutions for real-world multi-hazard scenarios.

MULTICARE will address this challenge directly by developing new multi-criteria decision-support frameworks and providing plug & play technological and digital solutions for improving the resilience of the built environment in a cost-effective, reliable and sustainable manner. The technological solutions consist of multi-functional low-carbon resilient technologies embedded in modular and prefabricated construction for the next generation of high performance and smart buildings, characterized by enhanced safety, energy efficiency, environmental-sustainability, improved quality of life, circularity, and scalability for a broad range of natural events and end-user. The plug & play technologies will be applied to either new multi-story buildings or existing structures by means of low-invasive external interventions. The digital solutions consist of a suite of multi-disciplinary digital services and tools for performing multi-hazard resilience assessment, design, operation and management across multiple scales (material, component, building, neighborhood/city). The new digital tools will enable stakeholders to make informed decisions in the selection of materials/solutions, including for heritage buildings, and support resilient supply chains. The effectiveness of the MULTICARE solutions will be demonstrated through large-scale pilots (3 buildings, 4 neighborhoods/district) in three different European countries carefully selected for their diverse local environmental, social and economic conditions (Italy, Netherlands, Romania). Banks and institutional investors will be engaged to better understand the financial risk reduction value of resilience and update existing and future “green finance” mechanisms that will help to leverage the project results. A user-center, inclusive and participatory approach will be consistently implemented throughout the project to engage citizens and extend the durability of MULTICARE impact.

To achieve these ambitious goals, MULTICARE brings together a unique interdisciplinary Consortium of 21 partners (Error! Reference source not found.) from 6 different EU countries w ith strong R&D and practical expertise, who are either established leaders in their sector or agile SMEs in emerging fields. Altogether the Consortium members span across the whole

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technical and value chain required for developing and implementing solutions in terms of design, digitization, manufacturing, construction and monitoring of resilient and sustainable buildings. The Consortium also includes partners with experience in social sciences, user engagement, and training to ensure the success and widespread application of new technologies in local communities. The Consortium will also support clustering activities with other relevant research projects to share knowledge and raise public awareness of building resilience. An international outreach and cooperation strategy will also be implemented to tackle the project challenges.

Table 1. Consortium

Number	Role	Short Name	Legal Name	Country
1	CO	TU Delft	TECHNISCHE UNIVERSITEIT DELFT	NL
2	BEN	PFE	PRIEDEMANN FASSADENBERATUNG GMBH	DE
3	BEN	IES R&D	IES R&D	IE
4	BEN	INCDFP	INSTITUTUL NATIONAL DE CERCETARE-DEZVOLTARE PENTRU FIZICA PAMANTULUI	RO
5	BEN	UNIROMA1	UNIVERSITA DEGLI STUDI DI ROMA LA SAPIENZA	IT
6	BEN	XLD	X-LAM DOLOMITI SRL	IT
7	BEN	STRESS	SVILUPPO TECNOLOGIE E RICERCA PER L'EDILIZIA SISMICAMENTE SICURA ED ECOSOSTENIBILE SCARL	IT
7.1	AE	UNINA	UNIVERSITA DEGLI STUDI DI NAPOLI FEDERICO II	IT
8	BEN	AMS Institute	STICHTING AMSTERDAM INSTITUTE FORADVANCED METROPOLITAN SOLUTIONS(AMS)	NL
9	BEN	PMB	MUNICIPIUL BUCURESTI	RO
10	BEN	ASM	ASM - CENTRUM BADAN I ANALIZ RYNKUSPOLKA Z OGRANICZONA ODPOWIEDZIALNOSCIA	PL
11	BEN	RoGBC	ASOCIATIA ROMANIA GREEN BUILDING COUNCIL	RO
12	BEN	RINA-C	RINA CONSULTING SPA	IT
13	BEN	UTBV	UNIVERSITATEA TRANSILVANIA DIN BRASOV	RO
14	BEN	ACER	AGENZIA CAMPANA PER L EDILIZIA RESIDENZIALE	IT
15	BEN	Boom	BOOM BUILDS B.V.	NL
16	BEN	OMRT	OMRT BV	NL
17	BEN	ROTHO BLAAS SRL	ROTHO BLAAS SRL	IT
18	BEN	ARUP	ARUP BV	NL
19	BEN	Tecuci	MUNICIPIUL TECUCI	RO
20	BEN	Hölscher	DIPL.-ING. HPLSCHER GMBH & CO.KG	DE

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1.2. Digitalization Requirements and KPIs

This deliverable outlines the Key Performance Indicators (KPIs, see Table 2 for summary) essential for evaluating the effectiveness of the MultiCare digital tools. The digital tools suite (hereinafter, the Suite) comprises several layers of distinct and / or complimentary software packages, interfaces modules and algorithms. These KPIs serve to shed light on, 1) the global performance of packaged systems, and 2) performance of individual components or features within a given package.

MultiCare's main digital developments occur in WS3 and WS4. WS3 develops resilience-based assessment and decision support tools at the building and urban scale. WS4 then develops multi-risk monitoring, early warning (EWS) and predictive systems. They digital systems are then implemented in real world demonstrators (WS6).

The suite must cater for users with different backgrounds and use-cases; thus, one set of users may report different experiences when assessing the same tool. Ultimately, every user of each tool has their own workflow and goals. These KPIs serve in part as a feedback mechanism within the design process.

Where possible, KPIs generally should have a baseline metric for comparison. Due to the novelty of the tools being developed specifically by MultiCare, direct comparisons may not always be possible. However, in some situations, one may compare the user's workflow or previous experiences before and after, by comparing to other software suites available in the open market.

1.1.1. Objectives

A holistic assessment of the digital demonstrators will be undertaken to provide a thorough analysis of the technical and non-technical performance of the digital tools. The assessment shall measure the software's ability to 1) perform its intended task, 2) the user experience (e.g., ease of use) while carrying out a task, 3) its general digital performance (e.g., querying time) and 4) its impact on pre-existing workflows, user perception and behaviour.

The objective of this deliverable is to define KPIs and describe their respective method of measurement.

1.1.2. Method

The determination of the KPIs outlined here primarily relies on the adoption of industry standards for the assessment of software products. The subset of KPIs measuring the technical (domain agnostic) performance of digital systems is based upon comprehensive literature reviews and industry standards. Domain specific (e.g., the performance of early warning systems) relies on literature review and discussion with consortium partners in industry.

1.1.3. Relation to other activities

The following **Table 2** illustrates the principal connections of this deliverable to other activities developed within the MultiCare project, which should be considered alongside this document to gain a deeper understanding of its contents.

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Table 2. Relation to other WPs

Work Stream	Legal Name
WS3 - Performance requirements, criteria and user's needs, and MULTICARE overall approach (D4.4)	This deliverable contributes to the establishment of the overall project concept by defining the methodology for evaluating the effects of interventions in the demonstration buildings
WS3 – Database of resilient components/systems (D5.3)	A database of pre-evaluated building systems/components. It can be used for informing optimal technology packages.
WS3 - Algorithms for multi-risk analysis of buildings (D6.2)	Algorithms for multi-risk analysis, with a focus on climate-related extremes. They enable to carry out loss modelling at building level.
WS3 - Plug-in for retrofitting design of heritage buildings (D6.3)	Plug-in for retrofitting design of heritage buildings. It enables multi-criteria decision-making analysis accounting for resilience indicators.
WS3 – Plug-in for tailor-based resilience design (D6.4)	Plug-in for tailor-based resilience design. It supports the building holistic design/renovation to construction/installation processes by assessing the feasibility of resilient systems and managing their integration with building components.
WS3 – Parametric tool for supporting resilience design (D6.5)	Parametric tooling for supporting the resilience design of buildings. It assesses the effects of different systems against different climates and hazards parametrically.
WS3 - Framework for energy network improvement (D7.1)	This deliverable provides a robust decision-making framework for assessing the responsiveness of districts energy network in case of disruptive events. It involves risk analysis and cost-benefit estimations.
WS3 - Multi-risk Spatial Decision Support System (D7.2)	This deliverable outlines the MULTICARE Spatial Decision Support System. It provides its initial validation for intervention planning at urban scale.
WS4 - Digital control system for facades (D8.1)	This deliverable provides the data acquisition and collection architecture of the facade monitoring system. It includes real-time sensing, visualization, data logging and processing.
WS4 - Digital control system for timber material (D8.2)	This deliverable identifies, analyses and selects sensors and monitoring solutions for engineered wood systems. It defines the implementation of the monitoring system for timber structural members.
WS4 - Maintenance and optimization tool for facades (D8.3)	Maintenance and optimization tool developed for building facades. The tool enables the control of the multi-hazard resilience level of facades.
WS4 - Seismic monitoring service (D9.1)	System to analyze sensors data and assess the difference in fundamental frequency. Analyses are carried out before and after retrofit and before and after a potential earthquake.
WS4 - Flash-flood and climate monitoring protocol (D9.2)	Flash-flood and climate monitoring protocol. A workflow and protocol for transmitting warnings when precipitation thresholds are exceeded.
WS4 - Overheating risk prediction and IEQ optimization service (D9.3)	Heat waves predictive warning services for building energy demand and Indoor Environmental Quality (IEQ) optimization. It improves comfort and well-being of building occupants during long lasting heat waves.

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WS4 - Seismic warning and rapid loss estimation service (D10.2)	Seismic warning system for earthquake detection and rapid communication. Rapid loss estimation service for assessing the overall post-earthquake impact.
WS4 - Flash-flood warning system service (D10.3)	Flood warning and rapid response system based on real-time monitoring. Specifically, it considers rainfall, river discharge values and flooded area extension.
WS4 - Method for time-dependent travel times (D10.4)	This deliverable provides the methodology for time-dependent estimation of travel times and isolated areas. It is based on a network-risk approach.
WS4- GIS service for time-dependent travel times (D10.5)	GIS service to enable the time-dependent estimation of travel times and isolated areas. It incorporates geospatial data such as 3D terrain model, buildings/addresses and live-traffic data.

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2. KPIs Definition

This section describes the defined KPIs for digital tools. **Table 3** provides a summary of the defined KPIs and their respective domain. The following sub-sections provide a more detailed description of the defined KPIs for each domain.

Table 3. Summary of KPIs

Domain	Index	Feature	KPI
Features and Functionality	FF1	Resilience Readiness Assessments for New Builds	Task Completion Rate
	FF2	Resilience Readiness Assessments for Existing Builds	Task Completion Rate
	FF3	Resilience Readiness Assessments for Retrofitted Builds	Task Completion Rate
	FF4	Calculation of: Circularity, Environmental Impact and Energy Assessments Metrics	Task Completion Rate
	FF5	Multi-scale Resilience Aggregation	Task Completion Rate
	FF6	Multi-stakeholder Utility and Accessibility	Stakeholder Satisfaction Score
	FF7	Information Content, Readability and Accessibility	Stakeholder Satisfaction Score
	FF8	Multi-criteria Decision Support	Task Completion Rate, Stakeholder Satisfaction Score
UI / UX	UX1	General User Experience	Stakeholder Satisfaction Score, Net Promoter Score
	UX2	Multi-stakeholder Utility and Accessibility	Stakeholder Satisfaction Score
	UX3	Time to Learn	System Usability Scale
System Performance	SP1	Processing Speed	Data Processing Time (s)
	SP2	Resource Usage	Memory Usage (gb)
	SP3	Querying and Retrieval	Data Retrieval Speed (s)
	SP4	Early Warning and Predictive Systems Accuracy	F1-Score, Confusion Matrices
Behavior Change	BC1	Risk Perception	Perception Change Survey Results
	BC2	Workflow Change	Workflow Change Survey Results
	BC3	Decision Change	Decision Change Survey Results

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2.1 Features and Functionality

Indicators which assess the achievement, or lack thereof of, [basic] functional requirements of the suite, encompassing both modular and packaged feature-based digital services. Functions listed hereunder correlate with the digital outputs expected from MultiCare.

Resilience Readiness Levels: Assessments and Design

Part of WS3's output is the development of a theoretical framework for assessing and designing multi-hazard resilient components, buildings, and neighborhoods. Tools developed in this WS will digitalize the framework and methodology into software packages. Indicators shall measure the success of users being able to successfully utilize the software for its intended purpose.

Feature	**KPI**
Resilience Readiness Assessments for New Builds	Task Completion Rate
Resilience Readiness Assessments for Existing Builds	
Resilience Readiness Assessments for Retrofitted Builds	

Circularity, Environmental Impact and Energy Assessments

In parallel to the tools which provide resilience assessment and design support, the software is expected to also be able to quantify the 1) environmental impact, 2) circularity and 3) embedded energy of various building components and interventions. Indicators shall measure the success or otherwise of users utilizing the software to carry out such tasks.

Feature	**KPI**
Calculation of: Circularity, Environmental Impact and Energy Assessments Metrics	Task Completion Rate

Multi-scale Resilience Aggregation

Digital tools shall be developed which integrate domain-specific methodologies for aggregating and extending a resilience metric from component to building level and finally to the neighborhood scale. This functionality is the basis of the spatial decision support system developed in WP7, while domain specific theory is developed elsewhere. Indicators shall measure the success or otherwise of users utilizing the software to carry out such tasks.

Feature	**KPI**
Multi-scale Resilience Aggregation	Task Completion Rate

Multi-stakeholder Utility and Accessibility

Indicators designed to assess a user-group's perception of the overall utility, i.e., the way in which a digital tool fulfills some technical need. Indicator shall assess across such the spectrum of user-groups.

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Feature	KPI
Multi-stakeholder utility and accessibility	Stakeholder Satisfaction Score

Information Content, Readability and Accessibility

General indicators used to assess the user-group's perception of the readability, legibility, and technical/non-technical accessibility of the output content (e.g., results of simulations) produced by the suite.

Feature	KPI
Information Content, Readability and Accessibility	Stakeholder Satisfaction Score

Multi-criteria Decision Support

Specific indicators used to assess the SDSS' intended functionality of supporting multi-criteria, multi-domain decision making. Indicators to be assessed across the user group spectrum.

Feature	KPI
Multi-criteria Decision Support	Stakeholder Satisfaction Score
	Task Completion Rate

2.2 User Experience / User Interface

General indicators used to assess the user experience as reported across the user group spectrum.

General User Experience

Indicators assessing the user groups reported overall user experience. Assessment focusing on packaged digital tools.

Feature	KPI
General User Experience	Stakeholder Satisfaction Score
	Net Promoter Score

Presentation and Visualization Satisfaction

Indicators assessing the user groups' overall satisfaction with the suites tool presentation of results (e.g., graphical representation, text, or report outputs.)

Feature	KPI
Multi-stakeholder utility and accessibility	Stakeholder Satisfaction Score

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Time to Learn

Indicators assessing the user groups' reported learning curve and the overall accessibility of the digital tools.

Feature	KPI
Time to Learn	System Usability Scale

2.3 System Performance

Indicators measuring the technical performance of digital tools, both in terms of computational efficiency (e.g., processing speed) and performance as intended (e.g., the accuracy of predictive systems).

Processing Speed

The execution time (end-to-end) of any data processing algorithms and pipelines.

Feature	KPI
Processing Speed	Data Processing Time (s)

Resource Usage

The efficiency of fast-memory usage required by a digital system.

Feature	KPI
Resource Usage	Memory Usage (gb)

Querying and Retrieval Speed

The execution time (end-to-end) of any data querying and retrieval performed by a digital system.

Feature	KPI
Querying and Retrieval	Data Retrieval Speed (s)

Early Warning and Predictive Systems Accuracy

The accuracy, precision and recall of any components of the suite which make predictions.

Feature	KPI
Early Warning and Predictive Systems Accuracy	F1-Score, Confusion Matrices

2.4 Behavior Dynamics

Indicators assessing the ability of MultiCare digital systems to effect change on a user's behavior, in terms of workflow, risk perception and decision making.

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Perception Change

Indicators assessing the user reported changes to their perception of risk (e.g., developing a greater risk awareness) before and after MultiCare digital tools.

Feature	**KPI**
Risk Perception	Perception Change Survey Results

Workflow Change

Indicators assessing the user reported changes to their workflow before and after MultiCare digital tools.

Feature	**KPI**
Workflow Change	Workflow Change Survey Results

Decision Change

Indicators assessing the user report changes into decision making process before and after MultiCare digital tools.

Feature	**KPI**
Decision Change	Decision Change Survey Results

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3. Evaluation framework

This section shall describe the method of formulation to be used for the 18 digital KPIs. Several indicators will utilize questionnaires, and it is outside of the scope (as well as premature) of this document to define questionnaire format and content. Some indicators may also take on the form of measurements and therefore require no formulation.

3.1 General Formulations

Several indicators share formulation, and common methods are listed below.

Task Completion Rate

Questionnaire based, where a pool of users reports whether they successfully complete a given task.

$$Task\ Completion\ Rate = \frac{No.\text{users who completed task}}{Total\ users}\%$$

Stakeholder Satisfaction Score

User reported metric, collected via survey, scaled score (1: very unsatisfied, 5: very satisfied). Measures the overall satisfaction of the user with the digital tool. Users may also report the reason for their score.

Note: This KPI is commonly referred to as *Customer* Satisfaction Score (CSAT).

$$Stakeholder\ Satisfaction\ Score = \frac{No.users\ who\ satisfied\ (score > 4)}{Total\ users}\ \%$$

Net Promoter Score

User reported metric, collected via survey, scaled score (1 to 6 = detractor, 7 and 8 = neutral, 9 and 10 = promoter). Measures the likelihood that a user would recommend a digital tool to another person. Users may also report the reason for their score.

$$Net\ Promoter\ Score = \frac{Promoters - Detractors}{Total\ users}\ \%$$

System Usability Scale

User reported metric, collected via survey, scaled score involving 10 questions (Brooke, 1995) with replies possible from 1 (strongly disagree) to 5 (strongly agree). Measures the overall usability of the digital tool.

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$$SUS\ Score = S \times 2.5$$

Where,
For questions 1,3,5,7, and 9 => score = Scale Position -1
For items 2,4,6,8, and 10 => score = 5- Scale Position
Summed Scores = S
Note: The factor of 2.5 applied to the summed score S normalizes the score to a maximum of 100.

F1-Score (Statistical Method)

The harmonic mean of a predictive systems Precision and Recall.

$$Precision, P = \frac{True\ Positives}{True\ Positives + False\ Positives}$$

$$Recall, R = \frac{True\ Positives}{True\ Positives + False\ Negatives}$$

$$F1\ Score = 2 \times \frac{P \times R}{P + R}$$

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4. Applicability to demonstrators

The KPIs described earlier apply to the following digital demonstrators.

Demonstrator	Features and Functionality	UI/UX	System Performance	Behavior Change
Acerra (Italy)	FF1 – FF8	UX1-UX3	SP1, SP2	BC1-BC3
Amsterdam (The Netherlands)	FF1 – FF8	UX1-UX3	SP1, SP2	BC1-BC3
Bucharest (Romania)	FF1 – FF8	UX1-UX3	SP1, SP2	BC1-BC3
Tecuci (Romania)	FF1 – FF8	UX1-UX3	SP1-SP4	BC1-BC3

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5. Conclusion

This document has set out a set of KPIs which will eventually guide the evaluation of the effectiveness of the digital tools developed by the consortium. It has laid out several user-centric KPIs in line with industry standards and the project's goals and ambitions. Several KPIs will collect data directly from a pool of users via questionnaire and interview processes. The design of such questionnaires is outside the scope of this document and will be defined prior to evaluation. As the project develops and the outputs made tangible, future refinement of this document in the form of re-issues may occur.

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6. References

Brooke, J., 1995. SUS: A quick and dirty usability scale. Usability Eval Ind 189.

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