INVITATION TO SUBMIT A RESEARCH PROPOSAL ON AN ASHRAE RESEARCH PROJECT

1929-TRP, Evaluation of building life cycle analysis tools incorporating embodied carbon

Attached is a Request-for-Proposal (RFP) for a project dealing with a subject in which you, or your institution have expressed interest. Should you decide not to submit a proposal, please circulate it to any colleague who might have interest in this subject.

Sponsoring Committee: TC 2.8 Building Environmental Impacts and Sustainability

Budget Range: $146,000 may be more or less as determined by value of proposal and competing proposals.

Scheduled Project Start Date: **April 1, 2024** or later.

All proposals must be received at ASHRAE Headquarters by 8:00 AM, EDT, December 15th, 2023. NO EXCEPTIONS, NO EXTENSIONS. Electronic copies must be sent to rpbids@ashrae.org. Electronic signatures must be scanned and added to the file before submitting. The submission title line should read: 1929-TRP, Evaluation of building life cycle analysis tools incorporating embodied carbon", and *"Bidding Institutions Name"* (electronic pdf format, ASHRAE's server will accept up to 10MB)

If you have questions concerning the Project, we suggest you contact one of the individuals listed below:

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Contractors intending to submit a proposal should so notify, by mail or e-mail, the Manager of Research and Technical Services, (MORTS) by December 1st, 2023 in order that any late or additional information on the RFP may be furnished to them prior to the bid due date.

All proposals must be submitted electronically. Electronic submissions require a PDF file containing the complete proposal preceded by signed copies of the two forms listed below in the order listed below. **ALL electronic proposals are to be sent to rpbids@ashrae.org.**

All other correspondence must be sent to ddaniel@ashrae.org and mvaughn@ashrae.org. Hardcopy submissions are not permitted. **In all cases, the proposal must be submitted to ASHRAE by 8:00 AM, EDT, December 15th, 2023. NO EXCEPTIONS, NO EXTENSIONS.**

The following forms (Application for Grant of Funds and the Additional Information form have been combined) must accompany the proposal:

(1) ASHRAE Application for Grant of Funds (electronic signature required) and
(2) Additional Information for Contractors (electronic signature required) ASHRAE Application for Grant of Funds (signed) and

ASHRAE reserves the right to reject any or all bids.

State of the Art (Background)

LCA tools and literature typically focus on the analysis of the various life cycle stages of buildings of various types following ISO14040. Studies often emphasize operational energy use and impacts over other life cycle stages (Ramesh et al. 2010) or building type and size (Sartori and Hestnes 2007, Monahan and Powell 2011). Early life cycle studies of buildings analyze several aspects of energy and environmental impacts, and as Kahhat et al. (2009) suggests, typically focus on the effects of energy efficient strategies, greenhouse gas emissions involved in the construction and production of the building, and variances in the different types of buildings, both commercial and residential. Some studies focus on the embodied phase (Monahan and Powell 2011) while others focus on the entire life cycle (Citherle and Defaux 2007, Marceau and Van Geem 2006, Monahan and Powell 2011, Kahhat et al. 2009, Keoleian et al. 2000, Ortiz et al. 2009, Sartori and Hestnes 2006, Stek et al. 2011, Ramesh et al. 2010).

Life cycle studies of buildings consistently reveal the embodied phase impacts of the building to be less than the operational phase impacts. As a percentage of life cycle energy, 9-10% for the embodied fraction is typical (Keoleian et al. 2000, Kahhat et al. 2009, Ortiz et al. 2009, Ramesh et al. 2010). Many of the early studies report the operational-use phase as the dominant phase of the life cycle unless the building is a self-sufficient one (Monahan and Powell 2011, Sartori and Hestmes, 2006) However as operational energy has fallen for new buildings, more and more attention is being placed on embodied energy and the associated carbon emissions.

The focus of many studies in recent years has been on reducing embodied energy and carbon emissions in a variety of building contexts such as building envelopes (Rock 2020), integrated cost and GHGE frameworks (Dahmen et al. 2018, Eleftheriadis 2018, Malmqvist et al. 2018, Schmidt and Crawford 2018) and smaller meta-analyses performed on embodied carbon assessment in buildings (Pomponi 2018). Recently, building information modeling-based frameworks have been used for minimizing building embodied energy (Schwartz 2016). Additionally, some studies focus on specific building designs and system components. (Vares 2018, Rodriguez, B.X., et al. 2020). Recently there has been some embodied carbon work on mechanical, electrical, and plumbing (MEP) and tenant improvements studies over a building life cycle (Rodriguez, B.X., et al. 2020) which found high carbon impact MEP components to be air handler units, duct work (sheet metal), light fixtures and cast-iron piping.

There are few efforts focused on the cataloging and evaluation or meta-analysis of current life cycle tools and literature specifically focused on building life cycle carbon (LCC) for building design and retrofits and most are focused on building envelope related aspects or construction materials (Olagunju and Olanrewaju, 2020, Rodriguez, B.X., et al. 2020, Emami, N et al. 2019, Takano et al. 2014) and none with a focus on formal software quality evaluations. Comparison of LCA tools often yields orders of magnitude differences in results (Emami, N et al. 2019, Takano et al. 2014) and understanding the contributing variables and factors to these differences are important. Uncertainty and accuracy of the models is also of concern.

Justification and Value to ASHRAE

This project will advance ASHRAE's commitment to the decarbonization of buildings and align with many of ASHRAE strategic research initiatives and task forces by focusing on the evaluation of tools, procedures, and methods for the design and retrofit of low-energy and low-carbon buildings through the lens of embodied carbon and life cycle analysis. Embodied carbon present in the production, installation and utilization of components and systems in building HVAC systems is an important design parameter of modern low-energy and low-carbon buildings.

This research project is in direct alignment with the ASHRAE decarbonization task force and is specifically addressing best practices for industry stakeholders including tools to evaluate embodied energy, embodied carbon, and the reduction of operational carbon. Additionally, the project will focus on knowledge gaps and the development of resources to address gaps by producing an evaluation of current software tools focused on LCA and LCC in buildings.

<u>Objectives</u>

The project will catalog and evaluate building LCA tools and related literature that incorporates LCC with the goal of providing ASHRAE an assessment of the "state-of-the art," and gap analysis that can be fulfilled by ASHRAE for ASHRAE members utility. Recommendations for potential improvements and identification of future research and development needs will then be formulated. This review and evaluation effort will summarize building LCA and LCC studies and programs that are focused on methods and models of building life cycle analysis. Some of these categories of evaluation include, but are not limited to, software robustness, accuracy, usability, compatibility, adaptability, customization, availability, cost effectiveness, and flexibility.

The evaluation of the tools will consider both a software quality evaluation (ISO/IEC 25010) and to ensure compliance with ISO 14040. Also, consideration maybe based on the applicability of life cycle databases and their locational relevance, adaptability and accommodating to new product data, software integration, and general utility and usability of the tool or method as well as the model's validation and verification according to best practices.

The researcher will perform the initial survey and refine the tools and literature to be evaluated. Model buildings and systems will also be finalized with approval by the PMS before the full analysis is performed. Upon approval by the PMS, the evaluation will be conducted, and the findings collated. The evaluation will not be picking winners or losers in the process or pass/fail indicators. The evaluation will identify gaps in the existing tools and literature with respect to the needs of ASHRAE members and will include making recommendations for the next steps.

<u>Scope</u>:

The project will entail two activity phases: Phase 1, in which the researcher will propose and finalize the building model(s) that will be used in the analysis and evaluation, conduct the initial software survey, and state the evaluation framework of analysis and evaluation. The evaluation framework will include the LCA scope boundary and software quality characterizations. Phase 2 will comprise the full analysis, evaluation and reporting of the results and gaps identified which will assist in the development of recommendations for future research and improvements. Those phases are described in more detail below.

PHASE 1: The objective of Phase 1 will incorporate three primary tasks: 1) propose and finalize, with the approval of the PMS, the building model(s) to be used in the project, 2) survey and catalog LCA tools and literature with a focus on estimating life cycle carbon for both new construction and retrofit projects, and, 3) finalize the framework of analysis and evaluation including LCA scope boundary and software quality assessment.

Task1. Commercial Prototype Building Model Discovery and Approval

DOE's Commercial Reference Building Models cover a variety of Reference Building types, and high-rise apartment buildings. With input from ASHRAE 90.1 SSPC, PNNL makes modifications to these commercial prototype building models as Standard 90.1 and IECC evolve. The researcher will choose a medium-sized commercial reference office building model from these reference types that will be approved by the PMS for use in this study.

Task 2. Survey and Catalog LCA Tools and Literature

Life Cycle Assessment/Carbon Accounting Software Catalog and Assessment

In the recent decade a variety of software from a variety of countries has been developed for life cycle assessment and in particular for buildings. Some LCA tools that could be considered in the evaluation are Impact Estimator, Embodied Carbon in Construction Calculator (EC3), Open LCA, Building Emissions

Accounting for Materials (BEAM), GaBi and Sima Pro, Tally LCA CIBSE recently beta product DT65 (Digital Tool). Table 1 below is a listing of these and their associated costs.

Table 1. A sample of LCA and Carbon Accounting tools and estimated costs.

LCA/Carbon Accounting Software	Licensing Cost (per user) (USD)	Country of original/management
Impact Estimator for Buildings	Free	Canada
EC3	Free	USA
Build Carbon Neutral	$3,000 annual	USA
Open LCA	Free	Germany
BEAM	$250 (donation)	Canada
GaBi	$1,500	USA
Sima Pro	$6,400 (expert class)	Netherlands
CIBSE TM65/DT45	$110	UK
Tally LCA (requires Revit from Autodesk_	$1,200	USA
One Click LCA	Varies based on complexity	Finland

At least five LCA software tools shall be included in the project assessment, the researcher can choose more at their discretion. At least three or more (if more than five are chosen) of LCA tools must be a non-free option. The list in Table 1, is not an exhaustive list and other tools may be suggested by the researcher for consideration and approval by the PMS. The researcher will be only reimbursed for the software and support that are purchased. The current budget for software and support is estimated up to $20,000.

The assessment will include a commercial model office building utilized by the building energy industry and, if available, building components and systems such as mechanical, electrical, and plumbing systems. Software evaluations will be based on a general software quality assessment approach such as ISO/IEC 25010 (see below) and the life cycle carbon at each of the life cycle stages. A comparison of the life cycle carbon outputs in kg of CO2 equivalents of the individual programs will be made by evaluation of the statistical variation, such as the coefficient of variation, also known as the relative standard deviation, which is the group standard deviation divided by the mean.

Task 3. Framework of Analysis and Evaluation Development

LCA Assumptions and Boundary Conditions

Building life cycles are typically divided into four stages, with each conceptual module labeled A1 through C4. An additional module, D, accounts for benefits outside the system boundary of the object of assessment, and it includes the benefits of recycling and reusing materials at end of life as illustrated in Figure 1. The system LCA boundary for this study will be set to include module "D" since this an effort to evaluate gaps and issues with current software. Figure 1 illustrates the typical life cycle stages used in building LCA and a typical EN15978 system boundary (A1-C4) depicting the product production, construction, use and end-of-life phases typically known as a "cradle to grave" assessment. EN15978 is the European standard that specifies the calculation method, based on Life Cycle Assessment (LCA) and other quantified environmental information, to assess the environmental performance of a building, and gives the means for the reporting and communication of the outcome of the assessment. The standard is applicable to new and existing buildings and refurbishment projects (CEN 15978 2011). The inclusion of module D will further press the LCA evaluation envelope beyond EN15978 to encompass the whole life cycle beyond the "grave."

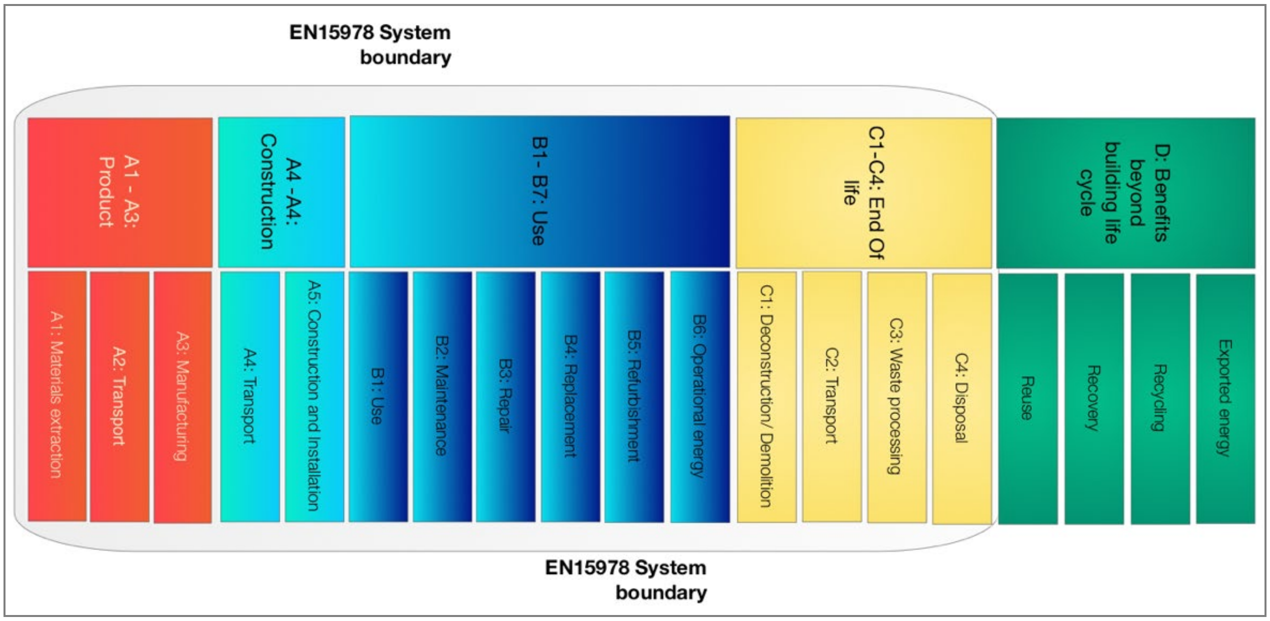

Figure 1. Building life cycle stages (A-D), EN15978 system boundary (A-C)

These different boundaries may affect the duration and accuracy or uncertainty of the results. The LCA software, utilized will be compliant to EN15978, but also be capable of extending to module D, benefits beyond the life cycle, such as recycling, reuse and recovery of materials or energy, so that a "cradle to cradle" approach is also considered.

Software Quality Assessment

The software quality standard ISO/IEC 25010 classifies software quality in a structured set of characteristics that can be used as criteria to evaluate LCA tools from a quality perspective. Some these specific characteristics relevant to this project are outlined below.

Functional Suitability – A set of attributes that bear on the existence of a set of functions and their specified properties. The functions are those that satisfy stated or implied needs. Items that can be suitable for assessing this quality are breadth of building material and component scope completeness, and correctness (accuracy), interoperability, and functional compliance such as to ISO 14040, EN 15978 and beyond EN15978 (Module D).

Reliability- A set of attributes that bear on the capability of software to maintain its level of performance under stated conditions for a stated period. Items that can be suitable for assessing this quality are maturity, fault tolerance, recoverability, and availability.

Performance Efficiency-A set of attributes that bear on the relationship between the level of performance of the software and the number of resources used under stated conditions. Items that can be suitable for assessing this quality are time behavior, resource utilization and capacity.

Usability- A set of attributes that bear on the effort needed for use, and on the individual assessment of such use, by a stated or implied set of users. Items that can be suitable for assessing this quality are understandability, learnability, operability, and accessibility.

Security – A set of attributes refers to how well a software system protects information and data from security vulnerabilities. Items that can be suitable for assessing this quality are confidentiality and authenticity.

Maintainability- A set of attributes that bear on the effort needed to make specified modifications. Items that can be suitable for assessing this quality are analyzability, reusability, modifiability, and testability.

Portability- A set of attributes that bear on the ability of software to be transferred from one environment to another. Items that can be suitable for assessing this quality are adaptability, install-ability, and replaceability.

Compatibility – A set of attributed the refers to how well the software can exchange information as well as perform it required functions while sharing the same hardware or software environment. Items than can be suitable for assessing this quality are co-existence and interoperability.

A software product is defined in a broad sense as encompassing executables, source code, architecture descriptions, and so on. As a result, a "user" extends to operators as well as to programmers, which are users of components such as software libraries. Some of the LCA software tools may be more or less open and extensible in this regard, as such the researcher, with approval from the PMS, will have the task of proposing the best characteristics and criteria for the evaluation. This may be done, for example, by specifying target values for quality metrics which evaluates the degree of presence of quality attributes. For example, the adaptability and accommodation of new product data should be considered. In these regards, the ISO/IEC 25010 standard provides a framework for the researcher to evaluate the quality of different software.

The methods used to do the building carbon accounting evaluation will include outlining the building environmental impacts accounted for within LCC (kg CO2 equivalent), in addition to other approaches such as complexity of life cycle software analysis, model accuracy and uncertainty evaluations, model limitations, associated tradeoffs and analytical cost (time). Accuracy and uncertainty evaluations will be researched in the survey portion of this phase and the researcher will propose method(s) to develop predictions on the life cycle accuracy and uncertainty estimates. This will an important part of the overall framework for the comparative assessment.

The completion of this phase includes all prior tasks including: 1) the building model proposal, 2) life cycle software catalog and proposal of tools to perform the assessment, and 3) proposal of the final framework for the comparative assessment, including prediction of the accuracy and uncertainty of the models. The PMS will meet with the researcher on a quarterly basis at a minimum during this phase of the project and this phase should conclude at month 6 of the project duration.

PHASE 2: Phase 2 will incorporate: 1) the full collection and evaluation of the findings of the surveyed catalog to identify gaps specific to MEP design in the existing tools and literature, 2) a comparative assessment of at least five LCA software tools including each of the four life cycle phases within EN15978 (product, construction, use and end-of-life), and, 3) to perform a software quality evaluation, including an evaluation of the accuracy and uncertainty of the models. The chosen building model will be utilized for the software comparison, including the simulation of the building envelope and the MEP systems present in the building. The research team should model the energy performance of the building based on the equipment and materials selection and use the associated operational energy and emissions in the life cycle analysis. Finally, the researcher will make recommendations for improvements and future work as requested.

The final project report will discuss and explore how the associated evaluation and gap-analysis will or could, with further development, integrate with existing building design or information management software workflows and provide improvements in the state of the art of design and retrofitting of low carbon buildings. The work effort in WS 1929 will not pick winners or loser or pass/fail type evaluations but seeks to identify the state of the art of the tools and current gap present in the software. A follow-on research project may be recommended if the existing tools are not useful for MEP design and recommendations to the modification or expansion of the capabilities and usability of the existing LCA tools could be considered. Another possibility is the development of a new application or method that can be easily used by building designers to minimize the impact of their buildings embodied carbon on the atmosphere.

The PMS will meet with the researcher on a quarterly basis at a minimum during this phase of the project and this phase should conclude at month 20 of the project duration. A mid-point PMS review of a minimum of two or three of the life cycle software evaluations at month 12 of the project duration, and 2) a final review of all the life cycle software evaluations at month 20 of the project duration.

A final evaluation and report, including all the work performed in Phase 1 and 2 and recommendations for future work, are due at month 21 of project duration for the PMS to review and provide feedback. After the PMS has provided feedback to the researcher on the report and analysis the Final report delivery will be due at month 23 of the project duration. At the conclusion of the project at month 24 a final presentation will occur.

Deliverables:

Progress, Financial and Final Reports, Technical Paper(s), and Data shall constitute the deliverables ("Deliverables") under this Agreement and shall be provided as follows:

a. Progress and Financial Reports

Progress and Financial Reports, in a form approved by the Society, shall be made to the Society through its Manager of Research and Technical Services at quarterly intervals; specifically on or before each January 1, April 1, June 10, and October 1 of the contract period.

The following deliverables shall be provided to the Project Monitoring Subcommittee (PMS) as described in the Scope/Technical Approach section above, as they are available:

Furthermore, the Institution's Principal Investigator, subject to the Society's approval, shall, during the period of performance and after the Final Report has been submitted, report in person to the sponsoring Technical Committee/Task Group (TC/TG) at the annual and winter meetings, and be available to answer such questions regarding the research as may arise.

b. Final Report

A written report, design guide, or manual, (collectively, "Final Report"), in a form approved by the Society, shall be prepared by the Institution and submitted to the Society's Manager of Research and Technical Services by the end of the Agreement term, containing complete details of all research carried out under this Agreement, including a summary of the control strategy and savings guidelines. Unless otherwise specified, the final draft report shall be furnished, electronically for review by the Society's Project Monitoring Subcommittee (PMS).

Tabulated values for all measurements shall be provided as an appendix to the final report (for measurements which are adjusted by correction factors, also tabulate the corrected results and clearly show the method used for correction).

Following approval by the PMS and the TC/TG, in their sole discretion, final copies of the Final Report will be furnished by the Institution as follows:

-An executive summary in a form suitable for wide distribution to the industry and to the public.
-Two copies; one in PDF format and one in Microsoft Word.

c. *Science & Technology for the Built Environment* or ASHRAE Transactions Technical Papers

One or more papers shall be submitted first to the ASHRAE Manager of Research and Technical Services (MORTS) and then to the "ASHRAE Manuscript Central" website-based manuscript review system in a form and containing such information as designated by the Society suitable for publication. Papers specified as deliverables should be submitted as either Research Papers for HVAC&R Research or Technical Paper(s) for ASHRAE Transactions. Research papers contain generalized results of long-term archival value, whereas technical papers are appropriate for applied research of shorter-term value, ASHRAE Conference papers are not acceptable as deliverables from ASHRAE research projects. The paper(s) shall conform to the instructions posted in "Manuscript Central" for an ASHRAE Transactions

Technical or HVAC&R Research papers. The paper title shall contain the research project number (1929-RP) at the end of the title in parentheses, e.g., (1929-RP).

All papers or articles prepared in connection with an ASHRAE research project, which are being submitted for inclusion in any ASHRAE publication, shall be submitted through the Manager of Research and Technical Services first and not to the publication's editor or Program Committee.

d. Data

Data is defined in General Condition VI, "DATA"

e. Project Synopsis

A written synopsis totaling approximately 100 words in length and written for a broad technical audience, which documents 1. Main findings of research project, 2. Why findings are significant, and 3. How the findings benefit ASHRAE membership and/or society in general shall be submitted to the Manager of Research and Technical Services by the end of the Agreement term for publication in ASHRAE Insights

The Society may request the Institution submit a technical article suitable for publication in the Society's ASHRAE JOURNAL. This is considered a voluntary submission and not a Deliverable. Technical articles shall be prepared using dual units; e.g., rational inch-pound with equivalent SI units shown parenthetically. SI usage shall be in accordance with IEEE/ASTM Standard SI-10.

Level of Effort

The level of effort is expected to include approximately 148 hours (about eighteen 8-hour days) for the principal investigator and 754 hours (about ninety four 8-hour days) for a research engineer. The estimated cost is $146,000, with 15% contingency and 35% profit and overhead included in this cost. The project is expected to take approximately 24 months to complete.

While the exact payment schedule will be negotiated between the successful bidder and ASHRAE, a proposed payment schedule is provided below

1. 75% of the total project cost for seven quarterly progress payments of $15,642.86 tied to project deliverables to be defined for a total of $109,500
2. 15% of the total project cost upon completion of the draft final project report for a total of $21,900
3. 10% of the total project cost for the completion of the project and final edits to the report for a total of $14,600
4. Software or support related cost delivered as needed or required.

Proposal Evaluation Criteria:

No.	Proposal Review Criterion	Weighting Factor
1.	Contractor's understanding of work statement as expressed in proposal Technical issues Analysis issues including a detailed plan for identifying the software to be analyzed and the model buildings, components, and systems	40%
2.	Qualifications of personnel included in proposal a. Principal investigator b. Research assistant(s)/junior engineer(s)	20%
3.	Institutional or corporate capabilities a. Performance on prior, similar projects demonstrated via references b. Administrative support capabilities as needed	20%
4.	Probability that proposed research plan will meet work statement objectives	20%

	a. Detailed and logical work plan with major tasks and key milestones b. All technical and logistical factors considered c. Reasonableness of project schedule	

Project Milestones:

No.	Major Project Completion Milestone	Deadline Month
1	Phase 1 completion includes 1) building model proposal, 2) life cycle software catalog and proposal of tools to do assessment, and 3) final framework of the comparative assessment	6
2	Phase 2 Mid-point review of a minimum of two to three of the life cycle software evaluations	12
3	Phase 2 Final review of all of life cycle software evaluations	20
4	Final Evaluation and Report includes collation of all the evaluations done in Phase 2, sensitivity and uncertainty research and analysis, and recommendation for future work	21
5	Final Report Delivery with edits recommended after Project Milestone 4 feedback from the PMS	23
6	Presentation of Results	24

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