# Baobab LIMS. A practical test evaluation in a small scale biobank


## Abstract

Laboratory Information Management Systems (LIMS) are valuable tools for automating and managing biobank operations. However, it is often a complicated endeavour to find a LIMS that incorporates and satisfy all possible requirements to the various workflows that a biobank may operates. In this regard, software testing helps in the mapping of user requirements to the software functionalities, and furthermore, it may reveal new user enhancements and functionalities. The tracking of changes in user requirements earlier in the development stages helps to avoid development process delays and the exhausting of funds which, when they occur may subsequently result in project failure. In this study, we present a tangible practical exercise of the open source Baobab LIMS in a small scale biobank, namely NSB. The study demonstrates the importance of such an exercise for both biobank and software sustainability.


## Introduction

The Bridging Biobanking and Biomedical Research across Europe and Africa (http://b3africa.org) is an EU-funded Horizon 2020 program. The B3Africa initiative aims to facilitate scientific research collaborations between African and EU States, to provide an ethical and legal framework to enhance mutual exchange of biospecimens and associated data, and to release an informatics platform, the eB3Kit, containing a variety of biobanking and bioinformatics tools to support research activities (Slokenberga et al., 2017, Soo et al., 2017).

To meet the above objectives, 8 work packages (WP) were created (Fig. 4.1), each of which was assigned predefined project deliverables (Table 4.1).

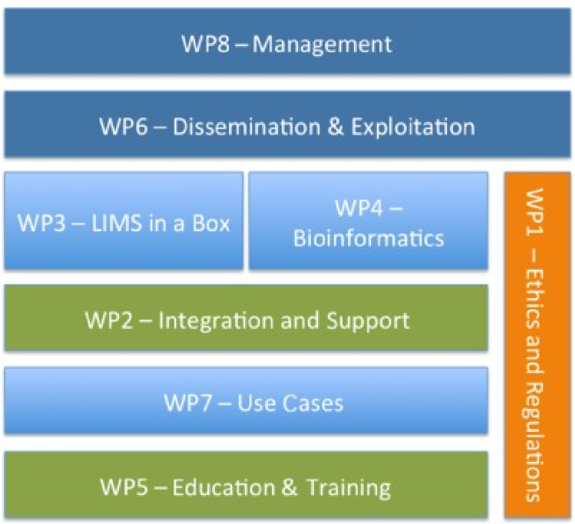


**Fig. 4.1** B3Africa work packages (http://b3africa.org)

In addition to the mentioned work packages in Table 4.1, associate (beta) sites formed part of the development process of deliverables to test proof-of-concept aspects that certain work packages were responsible for. For example, for Baobab LIMS development, WP3 worked closely with the NSB situated within the National Health Laboratory Service (NHLS) and Stellenbosch University (SU) at Tygerberg Hospital. The NSB is an example of a growing biobank, storing human biospecimens, and initially established as part of the H3Africa project, funded by the US National

Institute of Health (NIH) and the Wellcome Trust, to facilitate studies on health, disease and pharmacogenomics of African populations [link to nsb].

**Table 4.1** B3Africa work packages brief descriptions

| Work package | Description |
|---|---|
| 1 | Provides a framework of legal and ethical regulations, which enable biobank biospecimen and data sharing |
| 2 | Creates the technical framework for integration of open source tools and hardware to be used in biobanking and bioinformatics research studies |
| 3 | Develops and provides a Laboratory Information Management System (LIMS) to be integrated into the platform (WP2) and used in the proof of concept (WP7). The Baobab LIMS is the final deliverable by the South African National Bioinformatics Institute (SANBI), responsible for WP3 |
| 4 | Provides the bioinformatics framework for the B3Africa project. It will provide guidelines for the implementation of bioinformatics analysis pipelines, use and reuse of experimental omics data, and sharing of datasets and results |
| 5 | Develops and implements a package for education and training on the use of the platform, best practices in biobanking, bioinformatics data analysis, and data sharing, observing ethics and regulations |
| 6 | Disseminates knowledge about the B3Africa project, the B3Africa informatics platform, and the possibilities it will provide for biobanks and research groups in Africa and Europe |
| 7 | Implements a platform as a proof of concept. Several partner institutions will take part as use cases to test the harmonization of ethics and regulations, biobanking best practices (LIMS in a Box), bioinformatics pipelines, and education and training in the B3Africa platform |
| 8 | Deals with the day-to-day project management issues (strategic, financial and legal, innovation, coordination of Work Packages, quality and risk management) by the Project Coordinator and the Project Manager |

The NSB had initially not been using a LIMS to assist with the tracking of information and as such, had evaluated OpenSpecimen and Bika LIMS. However, both systems were found to be unsuitable for their biobank operations. Baobab LIMS, an open-source laboratory information management system, was therefore designed and developed by following the requirements and workflows of the NSB (See Chapter 3) (Bendou et al., 2017).

The workflow requirements of the NSB were translated into modules that constitute the core of the Baobab LIMS software. The design of the modules was performed in conjunction with the biobanking team situated at NSB. Following development of each module, a series of tests and demonstrations were presented to the NSB members in order to evaluate whether the module functionalities met the specified requirements of the biobank. Each module was subsequently restructured according to the feedback obtained, retested and demonstrated again to the NSB members. The cycle of feedback, updates, and tests was repeated until no further recommendation were made, and the module functionalities met the biobank specifications. The development of the Baobab LIMS followed the waterfall methodology for the first version but due to the increased interest in the LIMS, the Baobab team has expanded to include a full time software developer and a project analyst, and the next version of the software will be developed using an Agile scrum methodology. Sprints and milestones will be incorporated into the agile management system (Sliger, 2011) and will be invaluable in the development processes related to innovative requirements from biobanks.

System testing is described by the National Institute of Standards and Technology (NIST) as "the validation that the software meets its requirement. Validation of the complete system may involve many tests involving all system components. The software system tests exercise those system functions that invoke software to determine whether the software behaves as intended relative to complete system performance" (Klein, 2003). Furthermore, the Institute of Electrical and Electronic Engineers (IEEE) described acceptance testing as the operation that "checks the system behaviour against the customer's requirements (the 'contract'); the customers undertake (or specify) typical tasks to check their requirements" (Klein, 2003). The testing of any system is therefore vitally important to embark on prior to the implementation of the system.

To investigate the ability of the developed Baobab LIMS to be used in the automation and tracking of human biobank operations, the final product was implemented at the NSB biobank and the full functionalities were tested and evaluated in a practical exercise.

## Methods

*a. Test scenario*

The organisational structure of the laboratory based personnel working at NSB comprises of a lab manager, an IT system administrator, a lab clerk and two analysts. Throughout this exercise each user was assigned specific roles and tasks in the LIMS (Table 4.2). The laboratory of Professor Raj Ramesar (Division of Human Genetics) at the University of Cape Town is one of the NSB clients. The laboratory user accepted to participate in the test exercise and a project entitled "Baobab test case" had been agreed between both the lab managers. The client, for the purpose of this defined project, is assumed responsible for the collection of whole blood and urine specimens from two "pretended" (See next paragraph) participants. Consequently, the biobank assembled two kits, one kit per participant, each containing a barcoded BD EDTA vacutainer and an ACD vacutainer (Fig. 4.2(a)). The assembly process for each kit utilised products from the inventory storage. Both kits were packed according to IATA regulations and enclosed in a secure box, and were subsequently shipped to the client using the DHL courier services (Fig. 4.2(b) and 4.2(c)). It is important to note that the intention of this exercise was to evaluate the ability of Baobab LIMS to automate and track the information of the biobank and client operations. Therefore, to facilitate the progression of the exercise and avoid ethical and legal constraints regarding use of human specimens, the collection of whole blood and urine biospecimens were replaced with other non-human substances. Consequently, there was no physical testing of the quality of the biospecimens. However, the information was entered into the LIMS in order to ensure that tracking of analysis would have occurred and been recorded appropriately, if the samples were of human origin. The client received the shipment, collected the biospecimens from the consented research participants and were able to dispatch the shipment back to the biobank, using one of two possible methods; either by notifying the biobank to send a preferred courier to fetch the kits, or use the resources of the client for the dispatch. In this exercise, the former option was utilised and following notification from the client, NSB received the kits and ascertained whether all vacutainers and corresponding documentation are in place. For the assigned workflow, DNA extraction analysis followed by DNA purity and concentration assessment, as well as functional PCR were performed to determine the quality of the biospecimens. Following analyses, biospecimen qualities were reported to be deemed suitable in accordance to the biobank SOP and all biospecimens were stored in positions reserved in the biorepository freezer.

**Table 4.2** Biobank user roles and tasks

| User role | Tasks |
|---|---|
| IT system administrator | Install LIMS, create a clean Baobab site, manage the system, and create users with roles |
| Lab manager | Conclude agreement with the client, create project and specify the biospecimen types and analyses to be done to the client's biospecimens, and review analysis reports |
| Lab clerk | Manage biospecimen and inventory storage, make supplier orders, and assemble kits |
| Lab analyst | Create analyses, analyse biospecimens, and report results |


**Fig. 4.2** (a) Kit assembly process. The kit contains two empty barcoded tubes aimed to contain whole blood and urine biospecimens. (b) The shipment containing the kits is ready to dispatch. (c) Waybill showing the courier information and both biobank and client addresses. **(the (a) picture need to be changed)**

*b. Data Capture*

The Baobab LIMS used during the test exercise, is installed in a "built-to-specification" standalone personal computer (PC) hosted at the South African National Bioinformatics Institute (SANBI). The operating system for the PC is Ubuntu 16.04, whose official support is guaranteed until April 2021.

The PC station is characterised by the following features; 32GB Random Access Memory (RAM) and 2TB disk space. Access to the machine from outside the SANBI network is restricted by a firewall and as such, only the web server is accessible.

A clean Baobab site, named NSB, was created to track all possible information that could be extracted from the above test scenario. Baobab LIMS allows creation of more than one site in one Baobab LIMS installation. Each site will have its own users and information. This particular implementation can be important for a biobank with peripheral collection sites. Instead of implementing Baobab LIMS in every collection site, the LIMS application can be installed, for example, in the biobank IT infrastructure, and for each collection site a Baobab LIMS site can be created. The online user manual documentation was used as a reference guide during the data entry process (http://baobab-lims.readthedocs.io/en/latest/).

The interaction with the LIMS application began with the creation of the biobank and client users by the IT administrator. Roles, permissions and login access information were assigned to each user. The lab manager added a new project with all necessary information such as project title, description, number of participants, biospecimen types and analyses to perform on the client biospecimens. Inventory management, freezer management and order supply were responsibilities of the lab clerk. The user created '*BD EDTA*' and *ACD* vacutainers as products and placed an order for product supply. The quantities received were assigned to each product in the system. Using the kit assembly module, the lab clerk added two kits with the two empty tubes. Automatic barcodes were assigned to the two tubes and were recorded in the LIMS using the barcode scanner. A shipment record containing the two kits was added by the lab clerk. Additional information such as courier, client address, shipping dates were also provided in the shipment record. An automatic email was generated notifying the client of the arrival of the specific shipment from the biobank. The client used the LIMS features to acknowledge via email the reception of the shipment, and to notify the biobank, also via email, of the end of the process of collection. At the receipt of the biospecimens by the biobank, the lab analyst added the analyses and results of the biospecimen quality checks into the LIMS. The biospecimens were assigned storage positions in a freezer box that the lab clerk had created. The lab manager verified the results in a generated automatic LIMS report which was then sent as an email attachment, to the client.

*c. Evaluation*

The NSB group evaluated the laboratory information management system from different perspectives; (1) the workflow implementation covering the life cycle of a biospecimen from creation to complete use or destruction, (2) security and administration management, and (3) LIMS components; kit assembly, shipping, analysis request and freezer management. A simple method based on a numbering system from 1 to 5, with 1 being very bad and 5 being excellent, was used during the assessment of the Baobab LIMS performance (Table 4.3).

**Table 4.3** Numbering system based to evaluate Baobab LIMS

| **Value** | **Description** |
|---|---|
| 1 | Very bad |
| 2 | Bad |
| 3 | Satisfactory |
| 4 | Good |
| 5 | Excellent |

d. *Complementary test*

Following the NSB practical exercise suggestions, and to further demonstrate the strengths and weaknesses of the Baobab LIMS functionalities, similar evaluations were requested from and carried out by the Tunisian Pasteur Institute and the Uganda Biobanks. The Baobab LIMS online documentation was included in the assessments. The Pasteur Institute Biobank used the online documentation to install, setup and use in a production environment Baobab LIMS. Differently, the Uganda Biobank technicians were trained in a face-to-face training session before LIMS utilisation.

## Results

*a. NSB evaluation*

Table 4.4 summarises the results of the evaluation. All aspects were evaluated with respect to the numerical indicators (Table 4.3). The results of the evaluation demonstrated that the LIMS performance did not score below 4 for any aspects evaluated. One issue was reported regarding the online user manual guide. The lab manager commented that the online documentation was "very useful for an experienced LIMS user but could be daunting for a novice user". The lab clerk, suggested an enhancement functionality to support the storing of photographs of kits and/or individual barcoded biospecimens as they were shipped and received back from clients, for quality assurance and quality control (QA/QC). He also raised concerns regarding the freezer management component, suggesting that it can be difficult for novice users and proposed that more details pertaining to the module should be elaborated in the online documentation. The lab analysts further suggested that the addition of deviation codes (such as empty tubes, low volumes, cracked tubes) to biospecimens in a QC module would be beneficial. The documentation has since been updated, and ongoing work is in progress to add video tutorials for novice users. The other suggestions have been created as issues in the github repository (https://github.com/BaobabLims/baobab.lims) and will be addressed in the next versions. Some screenshots from the LIMS user interface have been provided at the Appendix B.

*b. Pasteur Institute and Uganda Biobanks evaluation*

Table 4.5 and 4.6 show, respectively the evaluation results from Tunisia Pasteur Institute Biobank and Uganda Biobank. The Pasteur Institute biobank scored at "4" the online documentation and suggested to more detail certain steps within the documentation. Two issues were raised regarding Kit assembly; encoding problem (Use of French special characters) and adding kits without registering a study project, one issue on using Freezer management; reagents cannot be added to freezer'shelves, and one issue concerning upload of user manual documents of laboratory instruments added in the Baobab LIMS. The last issue concerns the instrument module that is not included in the evaluation process. The shipping and analysis request modules are not used and are marked as “Not applicable”. Similarly, Uganda biobank assessed the Baobab LIMS online documentation at “4” and raised an issue regarding Plone dependency problem during the installation of the LIMS in a new Ubuntu 18.04 server machine. All the remaining modules were assessed at “5” (Excellent).

**Table 4.4** Baobab LIMS evaluation scores by NSB biobank

| Component | Description | Evaluation (1-5) | Issues |
|---|---|---|---|
| Workflow implementation | Biospecimen “life cycle” coverage, from collection to destruction, and the collection of key information such as the time the biospecimens arrived in the laboratory, company delivered, time and who accessioned biospecimens, the user that performed the analysis and the time of completion of the task | 4 | The one problem is that the online manual can create problems for a novice user |
| Security and administration management | Each NSB staff member and client will have specific assigned roles and a level of permission and security | 5 | No issues detected |
| Kit assembly | This component provides the protocol needed to assemble kits that will be used to collect biospecimens in the field | 5 | No issues detected |
| Shipping | The module ensures that the correct instructions are given to send the appropriate biospecimen containers (as packaged in the kits) to the client and subsequent email notification to alert the client of incoming kits | 4 | We have tested this module with our laboratory client and the processes were efficient |
| Analysis request | At the project level, analyses are defined for biospecimens based on the requirements of the project. Results of these analyses are registered and reported to the client | 5 | No issues detected |
| Freezer management | The module describes the physical storage in the NSB; rooms (within rooms), freezers, shelves, cryoboxes, and positions/locations | 4 | Documentation may confuse novice user |

**Table 4.5** Baobab LIMS evaluation scores by Tunisian Pasteur Institute biobank

| **Component** | **Description** | **Evaluation (1-5)** | **Issues** |
|---|---|---|---|
| Online documentation | The online documentation (http://baobab-lims.readthedocs.io/en/latest/) used to install, setup and use Baobab LIMS | 4 | Certain described steps need more details. |
| Workflow implementation | Biospecimen “life cycle” coverage, from collection to destruction, and the collection of key information such as the time the biospecimens arrived in the laboratory, company delivered, time and who accessioned biospecimens, the user that performed the analysis and the time of completion of the task | 4 | No issues detected |
| Security and administration management | Each NSB staff member and client will have specific assigned roles and a level of permission and security | 4 | No issues detected |
| Kit assembly | This component provides the protocol needed to assemble kits that will be used to collect biospecimens in the field | 3 | Problem with special characters (encoding) and we cannot add kits without having a project. |
| Shipping | The module ensures that the correct instructions are given to send the appropriate biospecimen containers (as packaged in the kits) to the client and subsequent email notification to alert the client of incoming kits | | Not applicable |
| Analysis request | At the project level, analyses are defined for biospecimens based on the requirements of the project. Results of these analyses are registered and reported to the client | | Not applicable |
| Freezer management | The module describes the physical storage in the NSB; rooms (within rooms), freezers, shelves, cryoboxes, and positions/locations | 3 | We cannot add reagents in shelf of refrigerator |

**Table 4.6** Baobab LIMS evaluation scores by Uganda biobank

| Component | Description | Evaluation (1-5) | Issues |
|---|---|---|---|
| Online documentation | The online documentation (http://baobab-lims.readthedocs.io/en/latest/) used to install, setup and use Baobab LIMS | 4 | Dependencies libxslt and libxml posed a very big problem to the Plone installation. |
| Workflow implementation | Biospecimen "life cycle" coverage, from collection to destruction, and the collection of key information such as the time the biospecimens arrived in the laboratory, company delivered, time and who accessioned biospecimens, the user that performed the analysis and the time of completion of the task | 5 | No issues detected |
| Security and administration management | Each NSB staff member and client will have specific assigned roles and a level of permission and security | 5 | No issues detected |
| Kit assembly | This component provides the protocol needed to assemble kits that will be used to collect biospecimens in the field | 5 | No issues detected |
| Shipping | The module ensures that the correct instructions are given to send the appropriate biospecimen containers (as packaged in the kits) to the client and subsequent email notification to alert the client of incoming kits | 5 | No issues detected |
| Analysis request | At the project level, analyses are defined for biospecimens based on the requirements of the project. Results of these analyses are registered and reported to the client | 5 | No issues detected |
| Freezer management | The module describes the physical storage in the NSB; rooms (within rooms), freezers, shelves, cryoboxes, and positions/locations | 5 | No issues detected |

## Discussion

The NSB evaluation exercise was beneficial for both the biobank and the LIMS developers. The biorepository group experienced an alternative methods, which was automated, organised and secure, contrary to the practices such as the utilisation of spreadsheets which create the risks associated to being stored in different locations, being accessible and easily edited by users without restrictions, and generating file versioning inconsistencies and potential loss of information. For the system developers there was a level of anticipation to see all components of the LIMS tested for the first time in a small biobank. The developers followed the exercise from the beginning to the end and as such, were on-hand for the possibility and appearance of unexpected bugs.

Fortunately, the abovementioned did not occur, and all the LIMS components worked efficiently. The exercise demonstrated the ability of Baobab LIMS to be used in the management practices related to biobank information. In addition, the test exercise revealed the importance of user feedback in the enhancement of certain modules, and the expansion of the LIMS with new functionalities. It is noteworthy to mention that many functionalities are commonly used in a multitude of biobanks, and as such, an enhancement feedback from a unique biobank may benefit multiple other biorepositories sharing the same requirements, as well as those which may expand to incorporate such functionalities as they grow and evolve.

According to (Davis and Venkatesh, 2004), the high rate failure which occurs in complex software development is caused during the requirements management processes and is greatly due to lack of user input, incomplete requirements and changing requirements. By including the NSB team from the early development stage, particularly with regards to the design of the Baobab LIMS modules, a successful software product which caters to the outlined biobank requirements, was created. At the end of each module development, the module functionalities were demonstrated to the end users. The demonstrations aided with increasing the user feedback whereby partially met and/or changes in the requirements were instantly tracked. Consequently, the LIMS software was delivered in the desired time, and ultimately, the test of the complete product functionalities described above, were evaluated with the best scores.

Baobab LIMS meets the needs of a biobank and in the above test case, it was demonstrated that the different modules are ideally suited to the functions of a small-scale biobank. Valuable improvements have been identified in the NSB evaluation exercise and forms the basis of a new specification for the next version release of Baobab LIMS. The suggested improvements concern the QA/QC module and the online documentation.

The QC modifications suggested by the biobank users are (1) new functionality to store photographs of assembled kits on the system at two separate times, before shipment and reception back from a client, to determine packaging damage and/or proof of arrival and acceptance into biobank as well as distribution, and (2) QC enhancement by adding deviation codes to biospecimens in case of handling issues and assigning function of process and/or storage. It is possible that throughout the overall process a kit or a biospecimen container may be damaged, or a biospecimen may fail initial acceptance and rejection criteria. In these cases, it is vitally important to capture this information as it will determine whether biospecimens will be accepted, rejected or flagged. This will have an effect on the final destination of the biospecimen especially for those that have been rejected and subsequently not processed and stored even though initial capture had occurred in the LIMS. In this way, pictures of kits and biospecimens taken before shipment, and following receipt from a client, allows for visual identification of the possible step which may have resulted in the operational procedure failure. Furthermore, a deviation code can be assigned to a biospecimen which precisely defines the cause of biospecimen rejection, such as, a missing biospecimen, a broken biospecimen, or a biospecimen of insufficient volume, to cite a few possibilities. The suggested improvements to QC are of value and importance to aid in the identification of error-prone operating procedures and as such, will affect decisions to enhance the procedures or to replace them with harmonized operating procedures (SOPs). Adherence to best practices and SOPs, from a national and/or international specialised organisation such as the International Society for Biological and Environmental Repositories (ISBER), may dramatically improve the quality of annotated biospecimens and the performance of biobanking services. Tools such as the ISBER online self-assessment tool helps biobanks to determine how well they follow the ISBER best practices and identify areas that need improvement. The self-assessment exercise is an important undertaking and should be performed before applying for certification and/or accreditation to International Standards Organisation (ISO) (ISO 20387 general requirement for biobanks currently under review) and certification programs such the College of American Pathologists (CAP) Biorepository Accreditation and the CTRNet Biobank Certification Program (Betsou, 2017). Certification and accreditation are regarded by external bodies (funders, researchers, ethics committees) as a proof of professionalism and ensures quality products and services by the certified and/or accredited biobank, and may therefore increases the biorepository usability and sustainability by attracting more users and funders (Barnes et al., 2016). Additionally, compliance to standards and adherence to best practices ensures that biospecimens originating from different accredited biobanks, to be used in a collaborative research study, are comparable in quality and exhibit reduced preanalytical variability. These combinatorial factors thereby provide high assurance of accuracy, reproducibility and comparability of the research results (Betsou, 2017).

With regards to the second area of concern, the online LIMS instructional documentation was described by the NSB users as "difficult and confusing for a novice user". The documentation used during the assessment exercise was written in a single PDF document. It is however understandable that placing all the LIMS information in one file may overwhelm readers. The updated online documentation is now written with Sphinx, (http://www.sphinx-doc.org/en/master/), a tool that makes it easier to create logical and visually appealing online documentation, in the format of an interactive website, with a possibility of integrating tutorial videos. The documentation was restructured and re-organised into 3 parts; the installation manual, the setup manual and the user manual, and in so doing, has made the documentation clearer, easier and more understandable (http://www.baobab-lims.readthedocs.io/en/latest). The new version of the online documentation was evaluated at "4" (Good) by both Tunisian Pasteur Institute Biobank and Uganda biobank. However, parts of the documentation remain unclear to certain users and need to be more detailed. For example, the users in Tunisia biobank were not being able to store reagents using the freezer management module. Furthermore, including warnings of dependency conflicts in the documentation will avoid users a long debugging process, that happened with the Ugandan users, which tried to install Plone in a non yet supported new released Ubuntu version. Nevertheless, The improved documentation can itself be used for self-training of a user, without recurrent face-to-face training sessions which requires individuals to travel to the respective sites and will, therefore, decreases the expenses of the biobank. This can be of particular application for biobanks with already limited resources. For example, the Tunisia biobank successfully implemented Baobab LIMS in a production environment using particularly the online documentation. The enhancement of the online documentation and the subsequent reduction in employee learning curve can therefore assist in reducing expenditures and ultimately increase user productivity and biobank sustainability (Lynch and Buckner-Hayden, 2010). However, training sessions of sufficient time periods help users to better understand the LIMS functionalities and their applicability to their appropriate biobank workflows. Therefore, the trained users from the Uganda biobank scored "5"( Excellent) most of the Baobab LIMS functionalities.

As previously mentioned, sustainability is the biggest challenge facing biobanks which operate under resource limitations (Abayomi et al., 2013). As such, open source LIMS may support biobanks in sustaining their operations by reducing the prohibitive cost associated with commercial LIMS in terms of license fees, implementation, support and training, and customisation (Kyobe et al., 2017). Furthermore, given the fact that practices vary depending on the type and scale of the biobank (Malm et al., 2013), customisation of LIMS may apply to adapt other biobanking practices. The open source aspect of Baobab LIMS allows for customisation of the source code by in-house biobank IT software developers with new modules specific to their biorepositories. Furthermore, the continued development of Baobab LIMS by the principle developers creates an environment whereby a community of engaged developers can be formed and possibly work together to contribute significant enhancements, ultimately aiding in the value and extended usability of a more universal LIMS.

The text encoding issue raised by the Tunisian Pasteur Institute biobank is related to language interpretation by Baobab LIMS. Consequently, the LIMS may not accept non-ASCII characters such as French special characters. There is already an ongoing work to translate Baobab LIMS and its online documentation in French, as it is an official language in many African countries, and use unicode encoding to accept non-ASCII characters. Acceptance of other languages in Baoabab LIMS will help non English speaking users to shorten the learning curve and therefore quicken the use of the LIMS.

Baobab LIMS provides users the possibility for storing and linking file documents such as user manuals to laboratory instrument records created in the LIMS. However, this functionality remains basic compared to specialised document store tools. WP2 responsible for BIBBOX, a platform of open source applications, has already integrated Baobab LIMS and tools for document storage.

The other problems raised during the different evaluations are created in Github issues and will be solved in future Baobab LIMS versions.

## Conclusions

Test exercises of a final software product by the customer (laboratory, or company) allows alignment of user requirements to the software functionalities, discovery of additional enhancements and new functionalities (that may be of great interest for customer), and also to improve robustness of the software functionalities. The test exercise of Baobab LIMS at the NSB biobank allowed for discovery of two valuable major enhancements that are indirectly related to the sustainability of the biobank; QC and online documentation. Following the success of the test case, the LIMS was also demonstrated and tested in other biobanks in Sierra Leone and Uganda. Interestingly, the biobank team at the Pasteur Institute in Tunisia, was able to successfully install, test and start utilising the Baobab LIMS in a production environment by exclusively using the online documentation, thereby, demonstrating the importance of this resource in training and LIMS implementation. Other suggestions and valuable enhancements were obtained from the above mentioned testing in other biobank cases, and are discussed in the next chapter; Future work and enhancements.