Retrieving Information from Hybrid Spaces Using Handhelds

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***Abstract*—Hybrid spaces consist of information resources of both physical and electronic form. With the advent of electronic publishing and WWW hybrid libraries became popular and widely acknowledged for their high informative quality and anytime availability. On the other hand, modern computing handheld devices and wireless communication networks can support their users in accessing and using these information volumes wherever a need arises. Therefore, the user can query an information system about the electronic resources and simultaneously explore the nearby physical resources, in a way that enhances awareness of available information collections and relations among them, and also create a new experience while seeking in a hybrid space. In this paper we present the design methodology of creating such a service in an academic library, as well as the evaluation model, the procedure and the results from assessing satisfaction for the use of that service. Our findings imply that users believe that the unified search for physical and electronic resources is an important feature when seeking information in big physical and electronic collections.**

***Index Terms*— evaluation; library service; mobile and ubiquitous computing; personal digital assistant (PDA)**

I. Introduction

This paper extends our previous work on creating and evaluating new services for hybrid libraries, which are supported by mobile computing devices, presented in UBICOMM 2008 conference [1]. During the last two decades technological advancements in the fields of computer technology, communication networks and electronic authoring and publishing resulted in a tremendous growth of data and information available to the public. The Internet and the World Wide Web successfully accommodated the majority of available computer networks, thus enabling data exchange and information sharing in a much faster way. During the 1990s, it was estimated that the Internet grew by 100% per year, with a brief period of explosive growth in 1996 and 1997 and nowadays the access and growth of available data is constantly increasing by orders of magnitude every year [2]. The information content created, disseminated and used has changed from static text to live and static multimedia, including plain and hyperlinked texts, raw data, audio/video files, images, and documents with spatio-temporal attributes. As of March 31, 2009 1.59 billion people use the Internet according to Internet World Stats [3].

To benefit from the wealth of information available libraries enrich their print collections with supervised digital sources, held either locally or in remote information organizations, such as digital libraries. Digital Libraries are information systems capable of keeping information content in collections of digital format and accessible by computers. Some of the best-known digital libraries are Project Perseus [4], Project Gutenberg [5], and ibiblio [6].

With the electronic information available evolving from structured (e.g., database tables), to semi-structured (e.g., metadata for texts and multimedia files), and unstructured (WWW pages), organization of the content had been ineffective and therefore new powerful information retrieval techniques should be implemented. Since the goal is not to just produce more data but actually to use them towards some purpose, information retrieval techniques needed to be adapted to the content evolution in order to provide valuable information to the users.

Unlike book collections, which are well structured and organized and a certain book can be easily located using author and title indexes, electronic semi-structured data follow organization principles and rules that are not very strict. As a result, indexes and logic-based query languages do not have adequate power to retrieve precisely information from the new collections. In addition, a great portion of the content provided from electronic collections is stored in distributed repositories, with different organization and metadata schemes. Due to the nature and organization of the new collections made available, new approaches based on different principles evolved, such as interoperability protocols and data integration methods.

Besides the wealth of information available, people are also interested in insights, i.e., in relationships among different data items to understand the true nature of things. Databases and search engines are not capable of pointing out these relations and therefore these technologies were supplemented using visualization and similar approaches, often called On-Line Analytical Processing (OLAP) tools [7]. These tools are well suited to gain insight from a structured source. However, they cannot provide further exploration leading to insights. Dr. Ramesh Jain [8] proposes the utilization of new systems, suitable to explore unstructured data and capable of providing to the user some insight to the information delivered. He calls them *experiential environments*. These environments can provide insight, by immersing the user to the data, allowing him to explore, experience and interact with it. In other words, they are used to bring the user into the information space available and assign him an active role in the information retrieval process, where relevancy of retrieved items is constantly evaluated and compared to nearby, related sources until the user gathers a list of data items to satisfy his information needs.

Access requirements also evolved in accordance to content and retrieval techniques evolution. It started with physical collections and local access, where the user needed to visit an information organization like a library to gain access to data items during office hours, and evolved with digital libraries and the World Wide Web to anytime access to remote systems, where the user can benefit from round-the-clock access services to digital and digitized information content. During the last years, we see one more evolution step; anywhere access to information content, i.e., the user is equipped with a mobile terminal which wirelessly communicates with computer networks and the Internet to access information content on demand, whether in an office, a teaching class, a park, or while traveling. Users are not concerned about the location of the data source as long as its quality and credibility is assured. They are interested in the result of data assimilation. Laptops, Personal Digital Assistants (PDAs), smartphones and Ultra Mobile Personal Computers (UMPCs) are some typical examples of popular mobile computing terminals to gain access to electronic information services. Using these devices, users can access traditional searching tools like library catalogs (On line Public Access Catalogs, OPACs) and indexes, as well as powerful search engines like Google and more sophisticated information retrieval tools, such as recommendation wizards, often used in large scale electronic stores.

In large public and academic libraries, such as the Library of Congress, the New York Public Library, and the Harvard Libraries, the two collections (physical and digital) are kept separately and as a result users can seek for information either by searching in the electronic catalogs from a PC or by walking to and browsing through the stacks. To avoid moving between the two spaces and overcome the discontinuity of searching in two different areas these spaces need to be brought close. The recent advancements in handheld computing devices like PDAs enable them with high resolution, colorful graphic displays, and wireless communication features. For instance, the device can wirelessly connect to a local computer network and the library's electronic services, and due to its inherent mobility its user can walk into the physical information space with an open window to the digital space, right on his palm. This allows for a uniform seeking procedure that integrates physical and electronic information collections into one, namely a hybrid information space that resembles the vision of Dr. R. Jain about experiential environments, where exploration and not querying is the predominant seeking interaction mode.

In this work we present the design procedure of creating a new library service that supports library patrons in seeking information within hybrid spaces using handheld devices, such as PDAs and smartphones. We also describe the evaluation phase of the design cycle, which aims at assessing the user satisfaction for the new service and present the derived results. Section II discusses related work in mobile computing for information services. The design procedure and service functionalities supported are presented in Section III. The evaluation method is described in Section IV and the results are presented in Section V. Section VI concludes this article with a discussion on the findings, limitations, and a brief description of future work.

II. Related Work

The potential raised by mobile devices in providing anywhere/anytime access to reference material and storing information locally, was quickly acknowledged by field practitioners, especially in healthcare environments [9]. In the beginning of the current decade several Health Sciences libraries, such as Libraries at Virginia Commonwealth Universities (VCU), were among the first to explore the PDA supporting services for medical doctors and paramedic personnel [10] [11] [12]. These mostly involved PDAs which were used for accessing reference content stored locally, such as the ePocrates clinical drug database and medical records, dictionaries and textbooks as well as writing and beaming prescribing aids.

Soon after these paradigms, devices where equipped with increased memory capacity, more efficient batteries, and higher resolution screens, making them all-around, valuable assistants for information advising. As a result there was a need for faster data exchange protocols, either wireline (Universal Serial Bus, USB) or wireless (Bluetooth and WiFi). Wireless communication features were a key factor in the usage and adoption of these portable-computing devices from a wide audience, since their users could also access and retrieve content not only locally stored on their device but also located in remote information management systems, such as digital libraries.

Buchanan, Jones, and Marsden [13] present an evaluation study on the usage of PDAs to access a remote Greenstone-based Digital Library. Their study focus mainly on the presentation issues occurring when searching and delivering content in small screen devices. However, no focus has been given to the usage of the PDAs in conventional libraries.

SmartLibrary [14] was a PDA-driven project started at Oulu University in Finland, where handheld devices were used to enable map-based guidance for book finding. A small search interface was used to submit a query to the library's OPAC and get a list of books that matched the searching criteria. Upon selection of a record from the list, the user could see its metadata and a small image of the library's floorplan, indicating the position of the book. Jones et al. [15] at Cornell University studied several application scenarios of wireless mobile devices in a library setting; these included query submitting to the OPAC from anyplace within the library, collaborative searching by leaving notes, sending emails, and communicating in real-time with group members while browsing the stacks in the library. In addition, the device could be used to capture some data from the books (e.g., by scanning or photographing part of it) and then moving the data to a laptop or desktop computer. However, neither in Oulu nor at Cornell universities access was provided to an information management system with structured and semi-structured data of electronic form, such as a digital library.

A closer approach to the usage of mobile computing devices to enrich information from the physical space with unstructured information (social tags and annotations) is the MoTag system [16], which uses PDAs to access G-Portal. G-Portal is a digital library of geospatial and geo-referenced resources that holds also social tags concerning the accessibility of public buildings and other similar structures. During their visit in a certain place, PDA users can search the G-Portal for any tags left by previous visitors, submit a photo of a location, create new tags, and also add comments and time-stamps. Similar examples come from the tourist industry and the museums. Many researchers have studied the use of PDAs in the context of city and museum guides [17] [18] for navigation and brief personalized information presentation [19] [20]. In these systems handhelds are used to display a floor plan of the current area. The map indicates nearby objects or exhibits which are available for the user to interact with in order to retrieve short descriptions about the objects and navigate in the area.

Most of the current research efforts focus on the development of applications that either facilitate mobile searching in the digital space or use the handhelds to provide navigation instructions in the physical space. Even though many libraries keep a wealth of recorded knowledge in both physical and digital form, to the authors' knowledge no studies have been made to assess the impact of a new mobile service that supports library patrons in seeking information in hybrid collections.

III. Developing the Prototype

This paper presents the design, implementation and evaluation of a service that uses handheld computing devices capable of accessing the Web to support students in searching and browsing large information environments, such as an academic library that holds data records in both physical and electronic form. In this section we describe the first stages of the design and implementation procedure, shown in Figure 1.

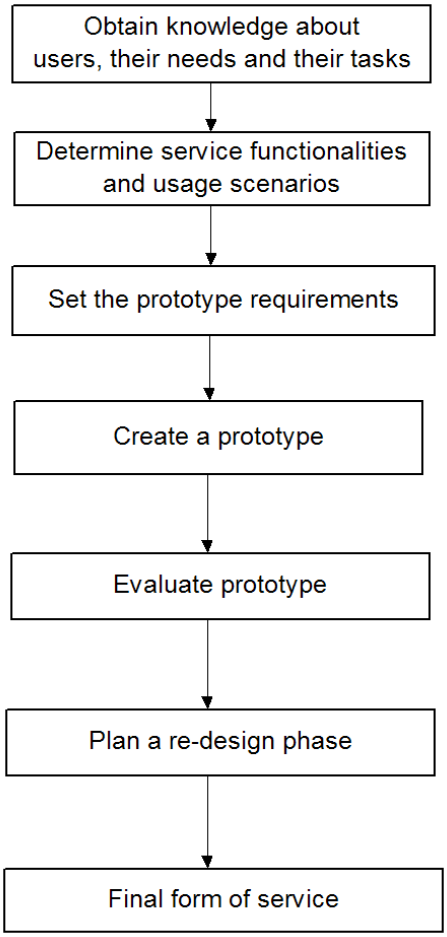

Fig. 1: Flowgram of the methodology adopted

A. The Methodology Outline

We started by conducting a focus group with 9 experts in the fields of computer science and librarianship to gain some insight of the typical library users, their needs, and seeking strategies. With this information at hand, the next step was to define the functionalities to be supported by the new service and create the necessary tools for these functionalities. Once the service functionalities were determined, we could create some typical usage scenarios to be used in our evaluation study.

The insight and data obtained from the focus group was used to inform the prototype design procedure, by providing guidelines on the interface design, set the requirements, and describe the service goals. We also had to extend the current infrastructure at the Library of Panteion University (Athens, Greece) to support wireless communication with the mobile terminals.

The next step was the design of the evaluation phase. We decided to follow a multi-strategy research, a term borrowed

from Layder [21], i.e., combine qualitative and quantitative research. More information on this kind of strategy can be found in [22]. During this phase we had to determine the research goals, determine the evaluation criteria and metrics to be used, construct a research model that visualizes the relationships among criteria, choose and create appropriate data collection instruments, such as interview guides and questionnaires, conduct a user study to collect the necessary data, analyze it, and finally report findings of our research.

These results would be used to start a redesign cycle, where prototype, scenarios, and evaluation procedure would be properly modified to improve the new service and gain some better insight to the extent that students accept it and embrace it.

B. Determining the Service Functionalities

The goal of this work was to create a new service that supports library patrons with handheld computing devices while seeking in both physical and digital information collections, in a unified way, by means of a user-centric approach, i.e., keeping the user active during the whole seeking procedure. Therefore, first we had to understand how students use the library's resources (catalogs, indexes, classification scheme, etc.) and identify any patterns in their seeking strategies and information needs. In addition, we had to explore the technical aspects rising from transferring the user-system interaction in a mobile context.

We chose to conduct a focus group in order to explore in depth these issues, both in terms of service functionalities and technical opportunities and constraints. We were particularly interested in how participants in the focus group discussion respond to each other's views and build up a view out of the interaction that takes place during the focus group discussion.

Blackburn and Stokes [23] found that discussion in groups of more than eight participants were difficult to manage. Therefore, our group consisted of 1 moderator, 2 observers, 5 librarian experts, and 4 experts from computer science. Four librarian experts were working in large academic libraries and one in a hospital library, and had a clear understanding of their library patrons and interactions with the library's resources. Two of the computer experts were working in ICT companies and the other two were working in universities in Athens, Greece. All participants joined the focus group after prior invitation. In general, invitations to group members were sent to people from the two fields that know each other, in order to explore collective understanding or shared meanings held within a work group, such as library employees.

Prior to the discussion, the participants were informed on the topics and procedure, as well as our intention to record the discussion in audio/video format. The participants received a list of scenarios making use of the functionalities for a proposed mobile service. These scenarios were derived from the literature and the participants were asked to provide their viewpoints for similar applications in a library. During the meeting they were encouraged to express their views on the proposed service functionalities so that we could study not only what they say but also how they say it, and how meaning is collectively constructed. The moderator would bring attention to specific points that are of potential interest to the focus group goals that they are not picked-up, and refocus the participants' attention to the topics of interest, in case the discussion goes off. The video recordings and the observer notes would later enable us to study and analyze the discussion.

Compared to individual interviews, focus group discussions many times appear to be less efficient due to several limitations. The following are some typical examples of these limitations; the extent to which it is appropriate to control the interaction between participants in order to have an in-depth discussion with multiple viewpoints and stay focused on the specific topics of interest; group effects such as dealing with reticent speakers and those who dominate the discussion. Asch's experiments [24] revealed that an emerging group view might mean that a perfectly legitimate perspective held by a minority of speakers may be suppressed. Therefore the moderator had to control the discussion and make clear that other peoples' viewpoints are definitely required.

To ensure that at the end of discussion we would have a clear viewpoint of each speaker on the topics and the proposed service functionalities discussed, we asked them to fill a short questionnaire used to express their attitude on a 5 -point Likert scale towards adopting (or not) the proposed information seeking aids.

To transcribe the focus group discussion we had to analyze data captured from two video cameras, a microphone, the observers' notes, and the questionnaires. We created a table in which each row represented a discussion topic, each column represented a speaker, and each cell included the corresponding time-stamped user comments, any observer notes, and the questionnaire score. These procedures allowed us to easily summarize the discussion, compare participants' viewpoints, and study the procedure of forming a group view.

To select the functionalities to be implemented for the new service we set an acceptance threshold, proposed by Nielsen [25], based on the emphasis given during the discussion; for a functionality to be selected it should (a) have an average score over 4, (b) at least 7 participants (80%) should have given it the top rates (4 or 5), and (c) no more than 1 participant (10%) should have given it the lowest rate (1).

The average values (AVGs) and the standard deviations (SDs) of the functionalities that survived the selection criteria were: (a) the wireless access to the OPAC and the e-resources of the library (AVG= 4.63, SD= 0.52), (b) the use of a map indicating a book's location in the stacks (AVG= 4.25, SD= 0.70), (c) the ability to communicate with the mobile device directly with other on-line users or send a short message/email to be received later (AVG= 4.13, SD= 0.99), (d) the ability to download/ save/disseminate electronic files retrieved, such as journal articles and lecture notes (AVG= 4.38, SD= 0.52), and (e) the ability of taking some quick notes either written or verbal (AVG= 4.0, SD= 0.75).

Service functionalities that did not survive the selection

criteria were mostly due to two reasons; privacy violation concerns and reduced utility value. These functionalities were: on-line user tracking to provide navigation instructions within a library setting (AVG= 3.5, SD= 1.20); storing user navigation routes to extract information about subject areas of interest and other preferences (AVG= 2.63, SD= 1.06); creating a patron profile to keep personal information (AVG= 3.50, SD= 1.20) that would be stored in the library's servers and updated from the student-system-content interaction in order to create content for personalized information services (e.g., alerts, notifications, recommendations, interfaces, etc.); wireless printing (AVG= 3.75, SD= 0.89) so that the students could immediately send a note or article for printing from anyplace within the library setting; route recommendation to collect books of interest (AVG= 3.00, SD= 1.20), which was shown not to be of particular interest to the students due to familiarity with the small size of academic libraries and the small number of books usually borrowed.

In addition, automatic metadata retrieval of books by detecting a Radio Frequency Identification (RFID) tag placed in the book (similar to scanning a barcode) was considered an attractive feature for the service (AVG= 4.13, SD= 0.64), especially when trying to detect and retrieve certain book or content within a stack. However, this feature was not implemented during the first design cycle due to extra equipment cost and time constraints.

With the service functionalities and corresponding tools determined, we could proceed to scenario descriptions, design requirements and guidelines, and prototype implementation. In a typical usage scenario a student uses the device to submit a query to the mobile OPAC. From the results list she sees the desired book and other related print works. Using the stylus she taps on the desired book to retrieve its metadata and sees that there are a few copies available on the shelf and a map indicating the location of the book in the stacks. While walking to the stacks to locate the book she activates her instant messaging (IM) account. Having found the book, she takes a quick note for the other related books of the author and sends a short question to the on-line librarian asking to inform her on due dates for previously borrowed books. Without needing to head for the computer room, she now searches the library's electronic resources for relevant entries. The results list shows a couple of records that seem relevant. She decides to download an article and send an email with its metadata, including a download link, to a colleague.

C. Designing and Implementing the Prototype

The focus group discussion revealed the need to design for users with diverse experiences, skills and knowledge concerning the information technology and collection usage, and cater for both novice and experienced users. In addition, we had to make the user-device interaction simple so that users could keep interacting with the physical environment and collections as much as possible, and spend their time effectively towards fulfilling their seeking goals. In other words, we had to keep their mental effort workload at low levels, so that they could keep touch with both information domains while seeking, despite frequent interactions.

Yet, the biggest challenge for the design phase was to create an interactive information service that would provide information on the spot, in the desired level, with flexible search options, via a device with constrained computing and interaction resources (e.g., processing power, screen size, and lack of keyboard). Whenever possible, interaction with physical objects, e.g., via metadata codes as information containers or pointers to other resources (Barcodes, Quick Response (QR) codes, RFID tags) should be exploited in order to speed-up the seeking process. That way, we can avoid unnecessary steps in searching, and further enhance experiential seeking and integration of the two information spaces (physical and digital) [26].

Regarding access to the service, it was decided that it would be implemented using a client-server architecture to reduce computing demands on resources to the mobile device, and that service should be web-based so that it can be accessed by any computing device capable of web browsing. Furthermore, we had to install a wireless computing network (WiFi Local Area Network) to make the service available from any place within the library setting.

In addition, the architecture should be modular to be easily upgradeable, i.e., each component in the architecture should be easily removed in the future and replaced by an improved version of it with better performance characteristics. The new service should also be designed for at least comparative usability to the currently available seeking service, i.e., catalog searching from a desktop terminal.

To create the new service, we consulted some of the most representative interface guidelines available; Shneiderman's and Plaisant's "Golden Rules for Interface Design" [27] and the "Ten Usability Heuristics" by Nielsen [28] apply to handheld design, since they are independent of specific technologies and device form factors. In addition, we considered basic design principles from "Apple Human Interface Guidelines" [29] and "Gnome Human Interface Guidelines" [30]. These guidelines typically include principles such as design for a variety of people profiles, using meaningful metaphors between application service and real world working cases, keep the application interfaces consistent, keep the user informed during processing and idle times, keep the interaction simple and pleasant, put the user in control of the interaction with the system, cater for simple and intuitive interaction, design well-defined dialogues, provide simple and unambiguous navigation, forgive the user when making mistakes, provide adequate help and examples for complex tasks, and provide feedback and communication on users' actions.

In addition, we studied three of the most comprehensive interface guidelines available for mobile devices; the PalmOS User Interface Guidelines by PalmSource Inc (now owned by Access Systems Americas, Inc.) [31]; Windows Mobile 6.0 - Design Guidelines by Microsoft Corp. [32]; and iPhone Human Interface Guidelines by Apple Corp. [33].

Palm presents some basic design principles and guidelines

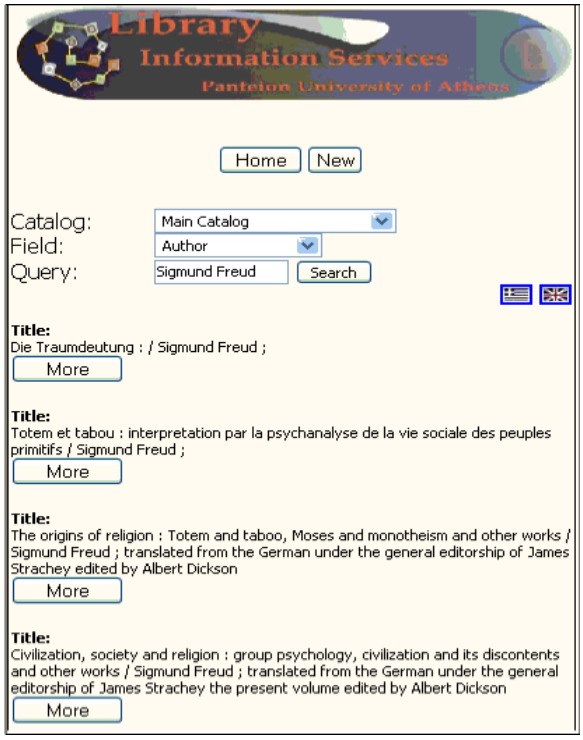

Fig. 2: The search interface for the mobile device

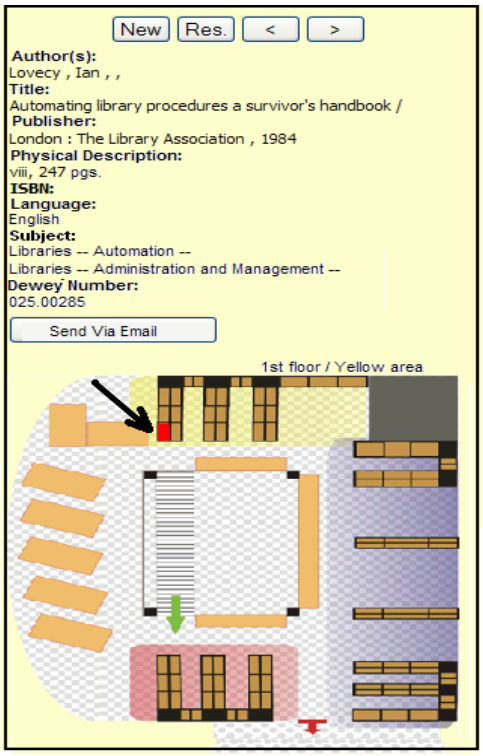

Fig. 3: Metadata for a record in the library's catalog (OPAC)

for the design process and concludes with recommendations and descriptions for getting feedback from the user and giving output back to him. Microsoft instead of giving some basic design principles, provides some application specific guidelines regarding home screen, web site design for mobile devices, navigation, screen rotation, soft-keys and menu operation, usability and interfaces for user-device interaction (e.g., screen layout and text input). Apple starts by covering the fundamental human interface design principles, describes how to apply them in designs for mobile applications, and moves on to description of the various views and controls that are available to the designer, along with guidance on using them effectively. Some of these guidelines are summarized here; design with pocket size in mind, i.e., limit data entry, hide unnecessary menus, do not use toolbars, provide only options that are usually needed to save screen space; keep interaction fast and simple by increasing speed and minimizing required steps to issue a command, and optimize frequent tasks; provide seamless connection with desktop computers since handhelds are used to extend desktop capabilities with the mobility feature rather than replace them; whenever possible choose "low-absorbing" interaction techniques and reduce short-term memory load to prevent user from loosing contact with the two information domains as a result of dealing with interaction issues; design for short, frequently interrupted tasks since the users will be moving in the library, thus constantly changing their working environment; ensure easy and permanent access to all library resources and areas where the user is expected to move; cater for effective and usable content delivery; design for familiarity with existing tools, i.e., use desktop-similar interfaces to benefit from usage familiarity.

To implement the prototype system we first had to create a mobile version of the search interface for the library's sources, suitable for small-screen devices. Two snapshots of the interface are shown in Figure 2 and Figure 3. The service is available from Panteion Library's website [34]. That interface would be used to build a searching query by submitting the searching term(s), the searching field (author or title), and the searching collection (either library's book catalog or the electronic resources). Upon a query submission a results list is sent back to the handheld and the user can tap on the record of interest to see its metadata. Each record from the physical collection is associated with a map indicating the corresponding item's location. For records in the electronic sources of the library, the user has the option of sending its metadata to an email account. These will typically include a downloading Uniform Resource Locator (URL). However, users are also allowed to download any available full-text material on the mobile devices. Furthermore, the instant messaging tool allows for short dialogs with other on-line users and library staff.

IV. Evaluation Design

Having developed the prototype, the next phase as shown in Figure 1 was its evaluation. The prototype described above was our first attempt to implement the new service and therefore a descriptive evaluation design (also called observational design) was adapted, i.e., an approach that would collect data of diverse nature (unstructured data from qualitative research

and structured from quantitative research). This is sometimes called a multi-strategy approach as mentioned earlier. The advantage of this approach is that it produces rich information content and insight from the data collected, which could not be reached by choosing either a qualitative or a quantitative approach alone. Many researchers argue that this triangulation can provide confidence in findings deriving from the study [35] [36], whereas not all researchers agree that a multi-strategy approach is always desirable or feasible [37] [38]. On the other hand, the amount of combined research in the social sciences has been increasing since 1980 [22].

Our evaluation objective was to study the usage of a new service in a library setting containing information in both physical and electronic format, and study the students' satisfaction and intention to use it. Particularly, we were interested in whether the mobility offered would be a valuable feature to the users while seeking in diverse information domains, and identify which factors and service capabilities mostly affected their interaction with the mobile device.

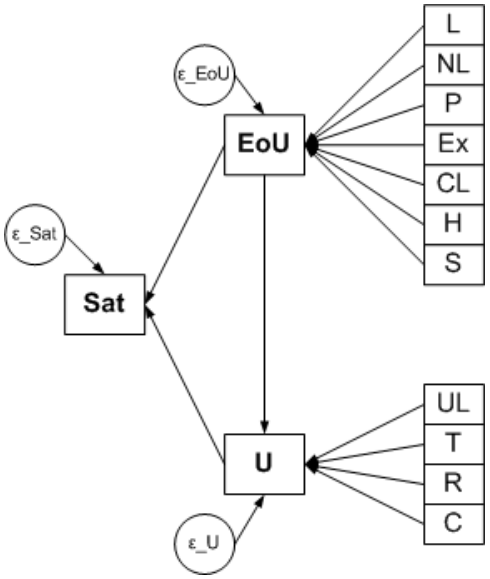

Fig. 4: Criteria and path relations of the evaluation model

A. Evaluation Criteria and Model

Several researchers agree that usefulness and usability are the most significant concepts for the user-centered evaluation of information services [39] [40]. Therefore, in a user-centered model that evaluates the impact of the new service to its users we need to examine the users' *Satisfaction (Sat), Usefulness (U),* and *Ease of Use (EoU)* towards that service and the effects between them. Usefulness is defined as "the degree to which a person finds that using a particular system or service will enhance his/her job performance". Ease of Use is defined as "the degree to which a person finds that using a particular system will be free of effort". We hypothesize satisfaction to be expressed in terms of usefulness and ease of use and positively related to both of them, i.e., the bigger the usefulness of the service, the bigger the user satisfaction. On the other hand, *Usefulness* and *Ease of Use* are complex constructs and therefore they can be broken down to simpler indicators that are easier to measure.

To assess the usefulness of the new service in finding and collecting the records of interest in hybrid collections, we use the following indicators (criteria): *utilitarian value (UL)*, which refers to the value the new service has in supporting the users to achieve their goals [41]; *time (T)*, which refers to the time earned from the usage of the service; *relevance (R)*, which refers to the relations among retrieved records from diverse information domains; *perceived completeness (C)*, which refers to the user's information needs obtained by the usage of the new service [42] [43]. Time saving and utilitarian value were addressed towards specific actions that were described in the scenario of Section III-B, such as information searching, file download and storage, communication, etc.

On the other side, ease of use is assessed by taking into account several interface attributes [41] [25], such as *learnability (L)*, easiness of transition between seeking tasks when following a *non-linear (NL)* seeking strategy, *organization and presentation (P)* of information delivered, *easiness of executing* and completing (Ex) the various seeking tasks, *clarity (CL)* and understandability of interaction with the service, on-line *help (H)* adequacy, and easiness in getting remote *support (S)* while seeking.

Table I summarizes the criteria referred in the bibliography and adopted in the present study whereas Figure 4 shows the relationships among them along with the corresponding error (ε) estimators. Relationships in the model described above can be moderated by various user-related factors; for example, users of different background, e.g., different level of computing experience, may perceive differently the ease of use of the new service. In addition, many usability studies have shown that user interfaces have a strong impact on Ease of Use. The current study describes our first evaluation approach in exploring users' attitudes towards the new service, and therefore its nature is rather exploratory than confirmative. For this reason, we do not pose and validate any testing hypotheses.

TABLE I: Evaluation criteria

Construct	Criteria
Ease of Use	a) Learnability, b) Task transition, c) Information presentation & layout d) Ease of task execution, e) Clarity, f) Help g) Remote support
Usefulness	a) Utilitarian value, b) Time saving, c) Relevance, d) Completeness

B. Experimental Setup

The next phase was to setup an experiment to collect data from users of the service. To recruit users we planned to have the evaluation conducted at an academic library (Panteion University, Greece), where students and academic stuff would

be typical users of the library. Since this was the first evaluation of the service we were mostly interested in collecting data and insight from a wide variety of users rather than a particular group (e.g., freshmen). Therefore all typical library patrons were eligible for participation in our data collection experiment. To increase the number of participants and reduce the experiment costs in terms of time and human resources, we asked for the contribution of teachers in 3 academic classes at Ionian and Panteion universities. Graduate and post-graduate students were motivated by their teachers to participate in the evaluation. They were encouraged to use the new service in order to collect bibliography records for their semester projects, resulting in 77 participants.

Prior to the experiment, participants were invited into a 30 minute briefing session where they were informed about the goal and the procedure of the experiment and also had a hands-on experience with the PDAs. According to the procedure, each student would borrow the PDA from the library's help-desk and would also be given a usage scenario similar to that described in Section III-B. Students were allowed to change the order of tasks described in the scenario, but they had to complete all the tasks. While participants were interacting with the mobile device and the service interfaces, their sessions were recorded (screen-captured) and transmitted in real-time to a remote PC. Two observers were also present to watch the interaction and guide the users through the procedure. The remote recording technique produced valuable content for the qualitative analysis of the next phase, in a way that is less intrusive to the experiment subjects. Upon completion of the tasks students either participated in an in-person interview or were asked to fill a questionnaire, describing some of their profile characteristics such as age, academic level and computing experience, as well as their experience from the interaction with the new service. Ten students were randomly chosen to be interviewed, resulting in 10 in-person interviews and 67 questionnaires (http://dlib.ionio.gr/hls/texts/evals/ev1/qsts).

V. Analysis and Results

In the following paragraphs we describe the analysis procedure and findings occurring from both quantitative and qualitative data collected from the evaluation phase.

A. Collecting and Analyzing Qualitative Data

The interview method was chosen in order to accumulate the users' comments aiming at a straight and representative qualitative evaluation of the validity of our research assumptions. The 10 interviews conducted where strictly personal in order to avoid any effect between the participants.

Semi-structured interviews were conducted based on both open-ended and closed questions to compensate for the drawbacks of each form. Two were the reasons for following the specific type of interview; the researchers intended to assure the aggregation of a minimum set of data and, on the other hand, to give the opportunity to the users to express their opinion freely without the interviewer losing control of the discussion.

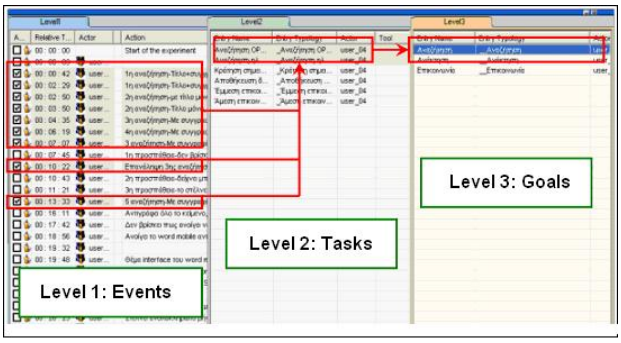

Fig. 5: Activity Lens: hierarchical view of multilevel analysis

Each interview lasted nearly 20 minutes and was recorded on video with the acceptance of the interviewees. Their opinions on usefulness, usability, and satisfaction for the new service were assessed using a 5 -point Likert scale (ranging from strongly disagree to strongly agree) against certain statements that the interviewer posed.

A remarkable amount of data was collected by the end of the interviews requiring an in depth analysis. For that purpose we used ActivityLens (AL) software [44], which is a tool especially designed to support ethnographic research studies and facilitates the analysis of data from multiple sources. These data can be audio/video recordings, log files, images, and text files (even hand-taken observation notes). AL permits integration and synchronization of the heterogeneous collected data. The AL environment was developed by the Human−Computer Interaction Research Group (HCI Group), of the Electrical & Computer Engineering Department, at University of Patras. AL was chosen among equivalent software, e.g., NVivo, Observer, and Transana because of its strength as a tool for qualitative analysis, its ease of use, the structural composition of data, and the full support that the creative team committed to offer.

ActivityLens supports hierarchical task analysis and therefore the recorded interaction of each user was classified in three levels of abstraction. We inserted coarse features of the collected data on the first level and extracted more qualitative results using the filters that the software offers on higher levels. At the lowest level (Operations or Events Level) the events for a task completion were annotated, according to a set of typologies; for instance an event could be annotated as "successful search to OPAC", "unsuccessful copy of metadata to the notepad", etc. In the middle level (Action or Tasks Level) the events of a user were grouped into tasks, according to the usage scenario, e.g., searching, typing, chatting, emailing, etc., with new typologies used to annotate the successful completeness (or not) of a task. Finally, at the third level (Activity or Goals Level) tasks were outlined as goals (seeking, communicating, etc.), while new typologies denote if the user achieved a goal. The hierarchical view of multilevel analysis is shown in Figure 5.

Regarding the users' profile it was found that more than half of the interviewees were visiting the library frequently

and were familiar with its physical space. In addition, 9 of them also use its electronic resources and 6 use web search engines in a daily basis. However, only 3 had previously used a mobile computing device, such as a PDA for an extended period of time.

The interviews revealed that users were very enthusiastic for the option of quickly searching in both information spaces from anyplace within the library, right when the need arises. This finding indicates the usefulness of the new service, which is also verified by the interviewees' Likert rates.

With most usability scores for the service interfaces above 4 (in scales ranging from 1 to 5), we conclude that the users found it easy to interact with the device. This was due to design resemblance of the mobile interfaces to their desktop counterparts. The most useful functionality was the capability of emailing the retrieved information (AVG= 4.44, SD= 0.73), followed by information storage in mobile disks, such as a memory card (AVG= 4.33, SD= 0.71). One of our participants emphasised on the usefulness of these functionalities by saying *"it is really important for me to store and send via mail anything that interests me the exact time that I find it, as simple as the pressing of a button"*.

Similarly the average usefulness of searching in the OPAC using the device was 4.33 (SD= 0.71), while it was found very convenient and easy to use it anytime/anywhere (AVG= 4.67, SD= 0.50), in contrast to the library's terminals. The usefulness of searching e-resources with a handheld was mostly affected by the relevance of the retrieved information (AVG= 4.11, SD= 1.05). This functionality also received a high usability score (AVG= 4.33, SD= 1.12). It is worth noting that those participants who quickly retrieved information records highly relevant to their interests, tended to perceive the functionality of searching in the electronic resources as the most useful. In addition, participants asked for the option of simultaneously choosing both collections (OPAC and e-resources) as searching targets.

Concerning the ability of taking quick notes, only three of the interviewees found it useful (AVG= 3.56, SD= 1.42) and reported that it was easy to copy/paste metadata (AVG= 4.22, SD= 0.97). The majority of our sample is used in keeping hand-written notes. In fact one of them mentioned: *"I always carry my own notebook and I am used in working that way. I can hardly change this habit even though I overcame all the usability problems that I came accross"*. On the other hand, 30% of our sample underlined the usefulness of taking notes on a handheld device because they considered it as a time saving procedure due to copy and paste commands available.

The video recordings revealed difficulties in text input using the virtual keyboard, which was a totally new experience for seven of the participants and gathered 45% of the complaints regarding the user-device interaction. The small screen size and stylus followed at 14% each, and the remaining 23% regarded navigation instructions, presentation style, device dimensions, and interfaces. However participants stated that after some training period these difficulties would not be strong enough to obscure the usefulness of the new service.

Some tasks gathered negative comments regarding their utilitarian value. At the bottom of the rank participants placed the use of the navigation map into the physical area (AVG= 2.33, SD= 1.66). Moreover the usability of this functionality was characterized indifferent (AVG= 3.0, SD= 1.22) and that was partly due to its reduced usefulness. Participants considered the service useful for new visitors, like freshmen, and for larger buildings. Surprisingly, one of the interviewees justified the lack of usefulness of the navigation map by saying *"It is boring to look for a book in the library. I prefer to ask directly the librarian instead of wandering through the stacks"*.

Furthermore, participants would prefer more vivid identification patterns, such as the existence of an indicator of the user's position in real-time. For similar reasons participants rated low the usefulness of the synchronous communication with the reference librarian (AVG= 3.22, SD= 1.39). Concerning the information completeness, they would like to have an indication of the number of hits in the search results as well as a relevance indicator next to each record.

Overall, the majority of the participants (nine out of ten) declared satisfied with the new service and they described it as innovative, interesting, and interactive. Anywhere/anytime access to the library's content and services is time saving and enables the users to easily swap the seeking target collection in an iterative fashion until they are satisfied with the resulting list. The meaning and the usefulness of the new service is reflected on the statement of one participant: *"The handheld device allowed me to implement a combined search to the hybrid information space, namely I can search and retrieve both books and electronic sources at the same time achieving more complete results"*.

Regarding the interaction with the mobile devices, users do not find the device's constraining resources (screen-size, lack of keyboard, low memory, etc.) to be a good reason to reject the new service. All of the interviewees intended to reuse the new service and recommend it to a friend or colleague.

B. Quantitative Analysis

All data for the quantitative analysis came from questionnaires that the participants used, in order to extract information about their profile and assess the evaluation criteria to be used. We used open-ended and multiple choice questions to collect these data. Questions regarding their user profile were coded using nominal variables (such as gender). Table II shows the frequency of their responses for their profile. We see that the majority of the participants in our study were female, active information searchers through the Internet channels and e-resources, and holding a bachelor degree.

Likert scales were chosen to express the extent to which participants agree (or disagree) to several statements, related to the evaluation criteria, such as *"It is easy for me to learn how to use the mobile device"*. Satisfaction (Sat) and perceived completeness (C) where assessed in 10-point Likert scales so that subjects could easier assess their attitudes towards these criteria. The rest of the criteria were assessed on 7-point scales. To proceed to the analysis stage, participants' responses

TABLE II: Frequency table showing the users' profile

Category	n	Percentage (%)
Male	18	26.8
Female	48	71.6
E-source usage	49	73.1
BSc level	53	79.1
MSc level	9	13.4
PhD level	5	7.5

TABLE III: Dominant predictors of user satisfaction

	B	SE B	β
Constant	0.35	10.95	
Time earned	5.08	1.28	.44*
Learnability	5.65	2.10	.31**
Completeness	0.20	0.80	.27***

Note: R^2= .57, *p≤.001, **p≤.01, ***p≤.05

were assigned to ordinal variables, i.e., besides recording an attitude/belief towards a statement we also recorded the order in which these attitudes occur. Like ordinal variables, interval (or scale) variables are used when the intervals between data points are equal for the whole measurement scale, so that there is a meaningful interpretation of the differences between data points. However, Jöreskog and Sörbom [45] suggest that an interval variable should be used only when data can be measured on at least a 15-point scale.

The statistical analysis is sensitive to missing data and there are several approaches available in statistical packages to handle such a situation [46]. For our analysis, missing values in the questionnaires were excluded pairwise, which means that if a person had a missing value for a particular variable, then his/her data were excluded from calculations involving only this variable.

For the current study we chose to use multiple regression analysis as a method of describing the relations and effects among the recorded variables, rather than predicting an outcome from recorded indicators. Having our model specified in Section IV-A the next step was to check whether the model can be identified. *Model identification* refers to deciding whether a set of unique parameter estimates can be computed for the regression equations. In other words, whether the number of parameters to be estimated equals the number of available equations. This occurs when the number of distinct values in the variance-covariance matrix (Table IV) of the indicators recorded, equals or exceeds the parameters to be estimated. Multiple regression models are always considered just-identified [47], i.e., all of the model parameters (beta weights or path coefficients) can be uniquely determined because there is enough information available in the variance-covariance matrix.

With our evaluation model identified, we can proceed to *model estimation*, that is compute the sample regression weights for the independent predictor variables. For these calculations we used the SPSS statistical package [48]. Stepwise regression analysis was performed twice, with the criteria presented in Table I used as independent variables, and Ease of Use and Usefulness as predicted outcomes. This analysis reveals which set of predictors is most important in explaining the variance in the predicted outcome, thus paying particular attention to them during development stages.

In the construct of *Usefulness* two independent variables were found to be the dominant predictors; *time earned* (t(57)= 5.190, p≤ .001) and *utilitarian value* of accessing the seeking service from anyplace within the library (t(57)= 2.267, p≤ .05). These criteria were found to account for 53% of variance in usefulness ($R^2 = .532$, $F = 32.346$, p≤ .05) and highlighted the fact that the participants perceive usefulness as the efficient access to resources from anywhere, in a ubiquitous fashion. As in the qualitative study, the navigation map aid and the assistance for locating books had no significant effect in usefulness and satisfaction, probably due to familiarity with the library environment and collections.

In the construct of *Ease of Use* five variables were found to account for 59% of its variance (R^2= .596, $F = 12.385$, p≤ .001): information *presentation* (t(42)= 2.826, p=≤ .01), *clarity* (t(42)= 2.763, p≤ .01), *easiness to execute communication tasks* (t(42)= 3.216, p≤ .01), *easiness to execute moving/storage tasks* (t(42)= -2.518, p≤ .05), and *help* (t(42)= 2.756, p= .01). The results of this analysis demonstrate the importance of interface characteristics and help functionalities in the perceived ease of use, as well as the easiness of executing crucial tasks that handhelds support.

Stepwise regression was performed to define which criteria from both categories are significant predictors of Satisfaction. In general the Ease of Use criteria account for 50.4% (R^2= .504, $F = 15.221$, p= .01), while the Usefulness criteria account for 48% (R^2= .483, $F = 26.679$, p= .01) in Satisfaction variance.

As shown in Table III three criteria were found to account for 57% in Satisfaction variance (R^2= .572, $F = 19,178$, p= .01). These are *time earned*, *learnability*, and *completeness* of the retrieved content. Figure 6 shows how this regression model of Satisfaction matches the recorded values for Satisfaction from the use of the new service. The three indicators reveal why participants are willing to use mobile computing devices in the library; it helps them in retrieving information content from multiple and diverse sources in a way that is quick and easy to learn.

The significance of the test statistics in our latest regression model does not mean by itself that there is a strong effect (relationship) between predictor variables and the recorded Satisfaction (recall that standardized β values indicate the relative importance of indicators in predicting an outcome). The importance of the chosen predictors is obtained by the effect size (ES), which is an objective and standardized measure of the magnitude of the recorded effect. The effect size is computed as ES= $R^2 - [p/(N-1)]$, where R^2= .572, p= 3 predictor variables and N= 64 observations (we used 64

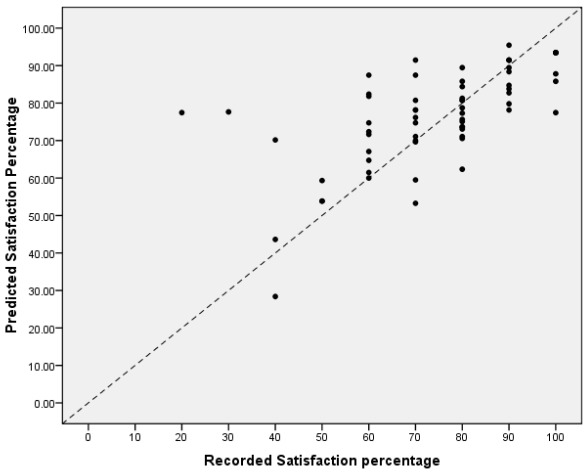

Fig. 6: Predicted satisfaction versus recorded satisfaction

measurements instead of 67 due to missing values). Therefore, $ES = .572 - [3/(64-1)] = .524$, which indicates a large effect size according to Cohen [49]. Miles and Shevlin [50] produced several graphs that illustrate the sample size needed to achieve different levels of predictive power, for different effect sizes, as the number of indicators (predictors) increases. From one of these diagrams we can see that for a large effect to be recorded and 3 predictors to be used, the required sample size should be approximately 40 participants. Therefore, with a sample of 64 subjects we can have confidence on the reliability of our regression model.

VI. Discussion and conclusion

This paper presents the design and evaluation procedure of a new library service that supports its users with handheld computing devices while seeking in hybrid information spaces. We described the stages of identifying the users' needs and service functionalities to implement, as well as the evaluation design, criteria, model, and methodology to assess their satisfaction for the new service.

We used a triangulation evaluation approach to assess the impact of the new service in the users' natural environment, i.e., a library setting. This approach included data from semi-structured interviews with the users, observation notes, video recordings from their interaction, and questionnaires administered to the users. This multi-strategy approach allowed us to gain better insights about the effect of the new service on the users and their needs. Besides studying how the service was used we were able to see and understand why was it used that way, i.e., study and analyze the non-linear seeking behavior of our experiment participants. In addition, qualitative findings helped us in better explaining relations among measurements and effects captured by the quantitative recordings. For instance besides describing the relation among measurement variables we could also explain and verify causality among them, which was used in our evaluation model specification. In general, the qualitative and quantitative findings provide valuable information, such as the fact that users envisage the proliferation of digital libraries by means of mobile devices, in order to raise space barriers, speed-up the seeking process and better experience the current information landscape that surrounds them. Furthermore users believe that the unified search for physical and electronic resources is an important feature with the interfaces kept as simple as possible, which was in agreement with the recommendation of experts.

The insight gained from this study provides valuable knowledge and data to proceed to inform decisions about the next phases of the service development. However, there are certain limitations in generalizing our findings to a bigger population. Our data come from a small sample size (N= 77), with participants from only 3 academic departments, i.e., social and humanitarian sciences. We can clearly see from Table II that their frequency distributions are far from uniform. In addition, all data recorded in the questionnaire are subjective measurements, i.e., they describe the users' attitudes towards various aspects of our evaluation criteria. Subjective measurements are always subject to bigger error levels and therefore reduce the explanatory power of our findings. To overcome this limitation we need to further explore the relationships and effects among recorded variables and use advanced statistical analysis techniques, such as exploratory and confirmatory factor analysis, which requires a much bigger sample of participants [51]. We also note that our model's fit index, to the data recorded, is R^2= .572, i.e., our model accounts for 57% of the variance in recorded satisfaction. In other words, more than 40% of variance is unexplained, indicating that we need to extent our evaluation model to include other factors that can have an effect in recorded satisfaction.

Therefore, based on the evaluation findings future work includes the extension of the prototype features in order to simultaneously submit queries in multiple sources and the resolution of interface problems that impede interaction. In addition, with the insight gained from the current study about the users' interaction with the service we plan to further continue our analysis with an experimental evaluation design, i.e., a design in which participants will be divided into two groups; test and control. This method enables us to investigate and better understand any effects and factors that significantly affect the users' efficiency while using a mobile device to seek in hybrid collections and therefore the new service's acceptance and usage.

Acknowledgment

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TABLE IV: The variance-covariance matrix for the recorded evaluation criteria

	Sat	U	EoU	L	NL	P	Ex	CL	H	S	UL	T	R	C
Sat	315.33													
U	7.70	0.65												
EoU	8.57	0.36	1.08											
L	6.94	0.33	0.30	0.94										
NL	2.67	0.10	0.00	0.48	1.27									
P	5.33	0.22	0.31	0.26	0.13	0.33								
Ex	8.34	0.47	0.34	0.79	0.63	0.34	1.27							
CL	4.08	0.13	0.26	0.16	0.10	0.11	0.13	0.42						
H	9.66	0.51	0.50	0.60	0.28	0.26	0.68	0.17	1.07					
S	1.62	0.04	0.40	0.07	0.51	0.24	0.17	0.01	0.03	2.12				
UL	4.90	0.39	0.17	0.30	0.25	0.13	0.43	0.08	0.44	0.13	0.81			
T	12.31	0.80	0.48	0.66	0.25	0.34	0.93	0.12	0.75	0.16	0.71	2.04		
R	6.70	0.21	0.39	0.29	0.08	0.20	0.34	0.19	0.42	0.12	0.24	0.45	0.75	
C	223.98	2.69	7.83	6.12	8.44	3.63	6.96	5.50	9.71	2.26	3.75	4.71	9.11	523.78