SNAGGING: AN INVESTIGATION OF MOBILE LOCATION-BASED SERVICES

Robert Amor, Professor, trebor@cs.auckland.ac.nz
Department of Computer Science, University of Auckland, Auckland, New Zealand
Dermott McMeel, Lecturer, d.mcmeel@auckland.ac.nz
Department of Architecture and Planning, University of Auckland, Auckland, New Zealand
Rowan Walker, Postgraduate Student, rwal137@aucklanduni.ac.nz
Sung-Whan Bang, Postgraduate Student, sban061@aucklanduni.ac.nz
Remy Lim, Research Assistant, rlim013@aucklanduni.ac.nz
Department of Computer Science, University of Auckland, Auckland, New Zealand

ABSTRACT

The proliferation of location aware smartphone and mobile devices enables a rethink and rework of processes on site and within a building. Existing laborious and paper-based processes such as defect identification in an almost completed building (snagging), facility management, etc can be significantly impacted through software on mobile devices which can calculate their exact position on the earth. A framework has been developed which meshes the major services required for such processes. The services investigated for this framework include: the provision and manipulation of 3D models on a mobile device; a number of location identifying approaches (e.g., GPS, Wi-Fi, QR codes); server-based database access to serve and store information; augmented reality (AR) overlays onto video streams; and CAD integration to allow for round-trip information flows between site and the office. To demonstrate the impact of this framework of amalgamated services an application has been developed to handle the snagging process carried out near the completion of a building project. Typically this requires all minor defects to be recorded on paper forms on site and then assigned to the various trades for rectification back in the office. Significant portions of the process are automated and enhanced by utilizing the developed framework.

Keywords: Mobile, Location-aware, Augmented Reality, Snagging

1. INTRODUCTION

The standard smartphone devices which are currently being purchased by consumers, and are in use by many in the construction industry, provide significant abilities. While the screen acreage may be fairly limited the screen resolution is high and the processing power of these devices is sufficient to furnish real-time 3D model navigation. These devices are also crammed full of sensors which can gather photos, video, compass direction, inertial movement, GPS location, etc. With their combination of Wi-Fi and 3G connectivity they can also send and receive significant amounts of information to undertake particular tasks.

The possibilities offered to location-based processes through applications on these devices appears significant and is being investigated in a series of research projects running between the departments of Computer Science and Architecture and Planning at the University of Auckland. Projects working around this theme are looking at: an interior design augmented reality application that determines actual room size; smartphone-based facility management processes tied to Building Information Modelling (BIM) models; a digital field-note collaboration system (McMeel and Amor 2011); and this project which is making the snagging process location aware.

The main technologies required to augment location-based processes are described below and then the requirements and implementation of the ARchi system which supports the snagging process are outlined in sections 2 and 3. Section 4 discusses the next steps to validate the developed system and is followed by conclusions and future work for this project.

1.1 The snagging process

The snagging process occurs towards the end of a construction process as a visual inspection of the constructed entity prior to handover and final sign-off. During this process the project manager, or architect, will walk through the completed building identifying minor defects, unsatisfactory work, and incomplete work. Many of the identified items are likely to be relatively minor (e.g., a cracked window, switches not square, paint scrapes, etc), though major issues may also be identified. The end of the process will be a snag list (or punch list in US parlance) with all identified items ready to be allocated to the particular trade or contractor to rectify. This paper-based process typically results in hundreds of items to be managed prior to the handover of any building and requires a significant coordination of tradespeople and contractors to ensure a satisfactory building ready for handover.

There have been a number of applications created to automate the snagging process, with a range of applications appearing for smartphone and mobile devices (e.g., in the iTunes (2012) store one can find the following applications: SnagR, Defects, PunchLists, dfectx, SiteWorks, Newforma Punch List, etc). Many of these applications purely automate the paper-based process for noting and managing the remedy of snags on site, though often with the capability to capture photos of the snag. Some of the applications now link with BIM data to allow the specification of the location of a snag directly on a plan for enhanced communication back to the contractors and tradespeople. However, these applications do not take advantage of the nascent ability of smartphones and mobile devices to determine their location on the earth, and hence their location in a building at the time a snag is identified.

1.2 Augmented Reality (AR)

Augmented Reality (AR) sits next to reality on the virtuality spectrum with its ability to take real world input and overlay it with computer generated information. It is this ability to enhance reality with ‘invisible’ information which has raised significant interest in the A/E/C industries where many processes are location-based and deal with products, services, and information which are not visible to the human eye (e.g., location of bracing in a completed wall, design parameters of systems in the building).

While a wide variety of technologies have been developed for AR (Carmigniani et al 2011, van Krevelen and Poelman 2010, Costanza and Fjeld 2009) a large portion of these are not suitable for on-site activities. For example, with devices that must be tethered to a computer, that require tracking systems to be preinstalled, or require delicate specialist hardware that would not survive a construction site. Significant research has also been undertaken in construction as to the benefits that AR might offer (Schall 2009, van Berlo et al 2009, Behzadan et al 2008, Izkara et al 2007), though often also with fairly specialized equipment which would not seem well suited to a construction site.

For this research project we were interested in utilizing technology which would be readily available to the professionals who are on site and would be able to withstand site conditions. As mobile phones are owned and used by the majority of workers on-site this technology, in the form of smartphones, was identified as well suited for the project. New smartphones have significant computational power, relatively low power consumption, sufficient screen size, low weight, and an affordable price (McMeel 2009, Izkara et al 2007) which make them a suitable technology.

AR has been demonstrated as a technology which can allow interaction with a BIM (van Berlo et al 2009) which is of particular interest in regards to visualizing construction projects in 3D as well as in 2D plan view. The ability to communicate in 3D is seen by many (e.g., Eastman et al 2011) as helping to bring construction information and processes to a wider audience (even through to lay people).

1.3 Location-based services

With smartphones incorporating location finding abilities it is worth considering the extra functionality which can be introduced to mobile applications which utilize this service. However, the traditional GPS location services are not well suited to many construction processes as signal strength drops quickly as one moves deeper into a building, and also working between buildings where the number of visible satellites is low also introduces error. For example, in tests around the buildings at the University of Auckland we identified location errors of up to 120m in some circumstances. Certainly of too large a magnitude to provide room-level location in a building. However, a range of alternate location identification technologies exist with varying levels of quality and ability to work in specific environments. A classification of technologies and their parameters is shown in Table 1 (Carmigniani et al 2011). Research around frameworks which will mix and match a range of services depending upon what is available at a particular location (e.g., Ficco and Russo 2009) provides a likely pathway for supporting construction processes.

Table 1: Parameters of location services (Carmigniani et al 2011).

Technology	Range (m)	Setup time (hr)	Precision (mm)	Time (s)	Environment
Optical: marker-based	10	0	10	∞	in/out
Optical: markerless	50	0–1	10	∞	in/out
Optical: outside-in	10	10	10	∞	in
Optical: inside-out	50	0–1	10	∞	in/out
GPS	∞	0	5000	∞	out
WiFi	100	10	1000	∞	in/out
Accelerometer	1000	0	100	1000	in/out
Magnetic	1	1	1	∞	in/out
Ultrasound	10	1	10	∞	in
Inertial	1	0	1	10	in/out
Hybrid	30	10	1	∞	in/out
UWB	10–300	10	500	∞	in
RFID: active	20–100	when needed	500	∞	in/out
RFID: passive	0.05–5	when needed	500	∞	in/out

2. ARCHI REQUIREMENTS

The main aim in this project was to investigate the infrastructure that would be needed to support computerized construction processes that were location aware. The interest in this question coming from the proliferation of mobile devices which support location identification within the construction professions.

The snagging process was chosen as the most suitable test for such an infrastructure as it combines the majority of the location aspects we were interested in exploring. Snags have a very specific location within a building and are linkable to specific objects in a BIM model. The snag information collected needs to be distributed to many participants on a project requiring communication on and off site. The professionals tasked with rectifying a snag need to navigate to the correct position on site when they undertake their tasks. The information collated for a snag is fairly small (requiring a small amount of typing) and can be augmented with photographic evidence. These attributes of the snagging process seemed to make it ideal as a case study for the location-based infrastructure we were investigating. The main requirements of ARchi were considered in the following areas.

2.1 Augmented Reality

The Augmented Reality (AR) capabilities required for onsite services push the boundaries of current consumer-level smartphones, with large building and site models needing to be rendered on the real-time video stream of the device. As well as the speed of rendering there is a need to ensure an accurate positioning of the virtual model onto the video stream to ensure a correct match between the real and virtual worlds. Given the size of models there will be some need to manage partial models and loading and unloading of these models as users navigate the site. The AR environment will need to allow the selection of an individual objects in a scene and to associate information with the object, or retrieve and display information about the object in the AR view.

2.2 Location services

Accurately determining a person's position on site or in a building through a consumer-level mobile device is the novel ability which benefits a significant number of processes on site. This enables identification of particular objects in the site and also navigation to these objects from any other point on site. A large number of location services are available, each of which has particular quality attributes (as in Table 1). As it is likely that several of these techniques will be available on each site we need a framework which can mix and match techniques to the particular location and need of a mobile service. As we are never likely to get a perfect match between actual and calculated locations it will also be necessary to allow the user to rectify the calculated location to match their actual location.

2.3 BIM

For location-based services there is a need to have detailed models of the site and building which will be navigated during the process. Typically this will be modeled in a BIM, CAD, or GIS system and needs to be provisioned onto the mobile device. For a number of services the ability to access partial models of a building for different domains is also important. For many processes, being able to maintain a bidirectional connection between the mobile system and the originating modeling system is also beneficial. For example, being able to see which BIM objects are affected by snags at the architect's office. This requires objects to be uniquely identified and linked between the mobile system and the originating BIM, CAD, or GIS system.

2.4 Information ecosystem

As the full set of systems which could be usefully connected to a location-based service cannot be determined up front, but is known to be large, it is beneficial to provide an open ecosystem which can be easily accessed by any tool. To support such an information ecosystem we specify a client-server architecture accessible over an IP connection as this works well with smartphone capabilities. The various types of data required for the application are served by a relational database which is available through a specific API on the server. This database can also provision its data in various formats to suit the needs of secondary applications (e.g., a CSV feed, or in XML).

2.5 Snagging process requirements

While the previous sections discuss requirements which are generic to a mobile location-based process there are a few requirements for the actual snagging process itself. A specific requirement for electronic snagging is that photos of the snag are able to be captured on site and stored alongside the snag specific data (this ability would also be useful in a number of other site-based processes). The snag specific data must also be collected and presented in the user interface and follows a fairly standardized format.

3. ARCHI IMPLEMENTATION

Over two years research students have worked on aspects of the ARchi system and crafted solutions to the various requirements of the system. Figure 1 shows the high-level system architecture employed in ARchi which comprises three tiers of services. The ARchi application for mobile devices on site is the user interface to provide the Augmented Reality (AR) environment which visualizes the BIM data (see Figure 3), allows for the management of snags (see Figures 2, 3, and 5), and collates raw position data. The server tier holds all data related to snags and the workflow currently in place around a snag. It also provisions BIM data as a 3D model and provides a positioning service based on location information fed from the mobile device. The office tier comprises application specific extensions which allow ARchi server connections to be established and information to be traded between the server and the central office application (see Figure 4).

Here we will look at how the ARchi system can be deployed differently on a smartphone and an iPad, to capitalize on the different strengths of the individual device interface possibilities. We will focus on an augmented reality smartphone implementation that manages snags by linking digital 3D models to a tag located in a real space; an iPad implementation that facilitates snag management while navigating a virtual building; server-end data storage and access; and a Revit add-on for importing snag information back into a BIM. The results of these implementations are discussed below.

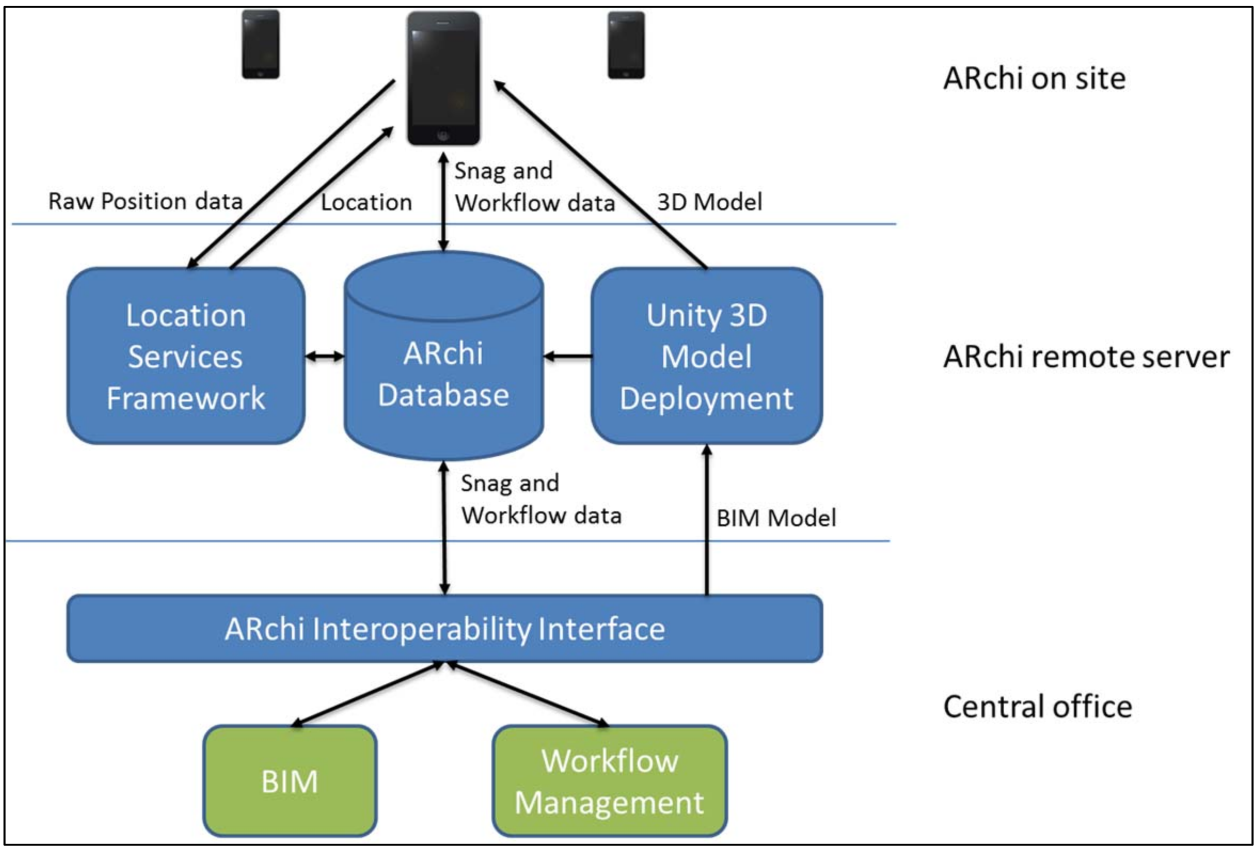

Figure 1: ARchi system architecture

3.1 AR abilities

AR interactions are well supported by the various open toolkits which are available (e.g., ARtoolkit), providing for recognition of tags and alignment of images with geo-located tags (see Figure 2). The tag recognition ability was found to vary considerably dependent upon the lighting conditions around the tag and the distance and angle of the smartphone in relation to the tag.

The provision of 3D models on a smartphone can be supported in many of the toolkits. However, as described by Boeykens (2011), game deployment environments such as Unity3D allow for sophisticated provisioning of 3D models onto a smartphone. We utilized Unity3D to develop a process for publication of segmented BIM models from Revit onto a mobile device, in this case an iPad. The segmentation of models was to ensure that the device's memory constraints did not interfere with the ability to navigate a complete 3D model. By specifying triggers on specific locations in the 3D model that allow transitions between storeys in a building (e.g., stairs and lifts) we were able to load and unload a complete storey of the model as the user moved up and down in the model. While Boeykens (2011) identified that Unity3D allowed for the management of textures in a BIM model through to the mobile environment we still experienced difficulties in ensuring a smooth transition of anything apart from plastic colours in the models that were published to the smartphones.

Alignment of the 3D model to tags within the smartphone view was well supported by the open AR toolkits, though the refresh speed of the model display was not sufficient to keep up with normal movement of the smartphone by a user on location.

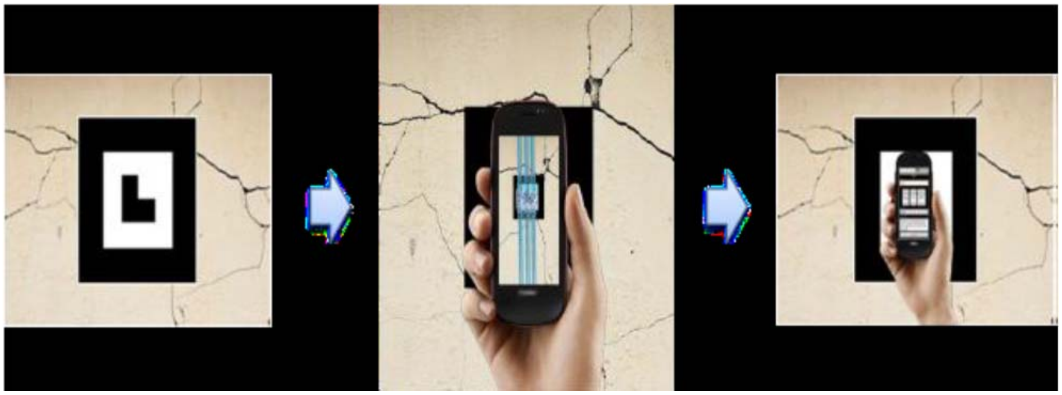

Figure 2: Tag detection leading to BIM model overlay and Snag information

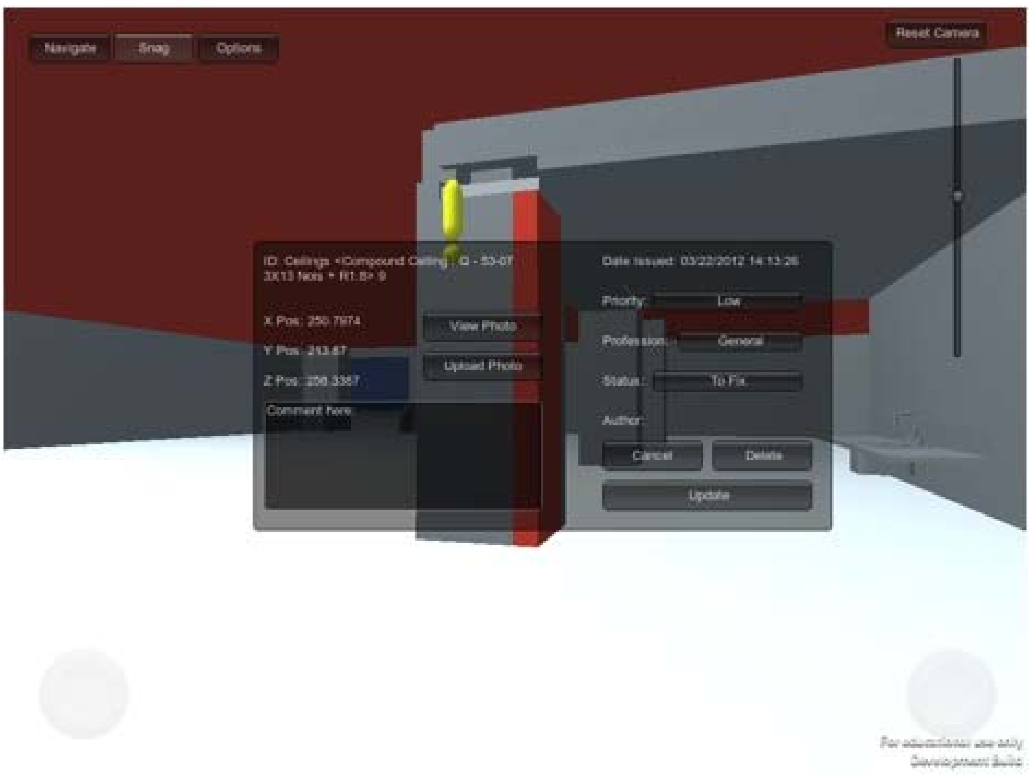

Figure 3: Navigation and management of snags within a 3D model on the ARchi iPad implementation

With the client-server architecture described in Section 3.4 it was possible for the snagging application to both create new snags in the database for use by other downstream applications, and to query the database to provide the user with up-to-date information on the status of work on any snag visible on the site.

3.2 Location services

The provision of an accurate location within a building proved to be the most problematic aspect of the project. As already identified, the use of GPS services within a building was highly inaccurate and other location services required significant setup to ensure accuracy (e.g., approximately 3m accuracy with Wi-Fi but only after all Wi-Fi routers were mapped in a building). Where tags were identified by the smartphone there was 100% accuracy as the BIM model could be interrogated to find the position to within a millimeter of the recognized tag. However, for the snagging process the density of tags did not allow for a tag to be in the smartphone field of view at all times.

Figure 3 demonstrates the ability of the ARchi iPad implementation to highlight objects from the BIM model based on an identified tag. The information box appears automatically upon selection revealing details about the object and snag. If the user changes information and presses 'Update' the snag is immediately updated on the server-end database. As long as the correct geo-location information was provided when publishing the BIM model through to ARchi (e.g., north point, reference point on the building, scale, etc) it is possible to use the ARchi Revit add-on to import snag data back into the BIM (Figure 4).

As the user's actual position could not be identified to within a unique space in the model it was necessary to provide the user with controls to move the estimated position to their actual position prior to specifying the location of a new snag. In Figure 3 the user controls for performing this navigation are visible at the bottom left and right of the screen. Once this real location was determined it was then possible to associate a snag's entry with a BIM object and hence accurately locate it within the model.

As a tag is accurately located within a BIM model it then becomes possible to provide guidance to a user to navigate through a building to the location of a snag. Both 2D and 3D models were tested for such navigation with a user preference for 2D plan views for this navigation process (such as provided by Google maps).

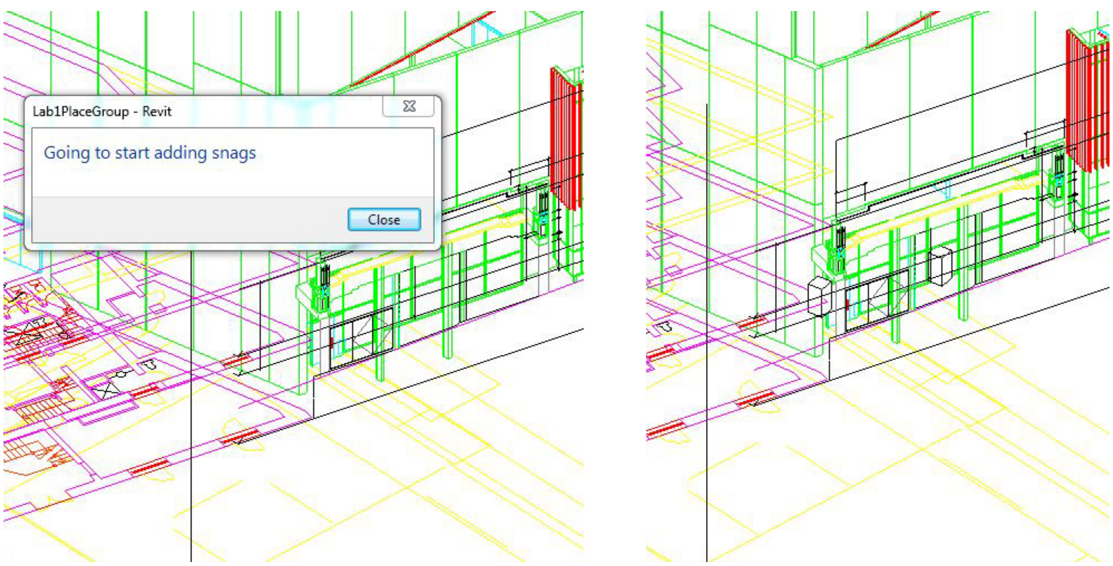

Figure 4: Snag objects introduced into the BIM system (Revit) from the server-end with our proprietary add-on

3.3 BIM interactions

The ability to round trip information from BIM through to the snagging application and back again was a major consideration for the project. While it was clear that BIM information was necessary to provide a context within the AR application (i.e., the 3D context of the building model and various layers in the model) there was also a potential to feed back into the BIM model. By maintaining a linkage between unique objects in the BIM model and the objects rendered in the snagging application it was possible to feed back information on snag issues to the designers working off site. Figure 4 shows the add-on we created for Revit which allowed it to call up snag data provided by the mobile implementations of ARchi and visualize it within the BIM model. All information about a snag as published by the mobile application could be pulled through to the Revit model and browsed by the user of the BIM software.

3.4 Information ecosystem

The utilization of a client-server architecture for the snagging application allows for a separation of concerns between the functionality of the mobile application and the needs of other processes which consume the data created by the snagging application. With a centralized database being updated and queried by the snagging application it has been possible to publish the snag information in the formats required by other applications.

As described in Section 3.3 this includes the structure required to update a Revit model, but also in CSV format for importation into a workload management system. With the server-based database operating as the canonical form for all snag related information it is possible to update and publish snag-related information to any consuming application without impact on the mobile snagging application.

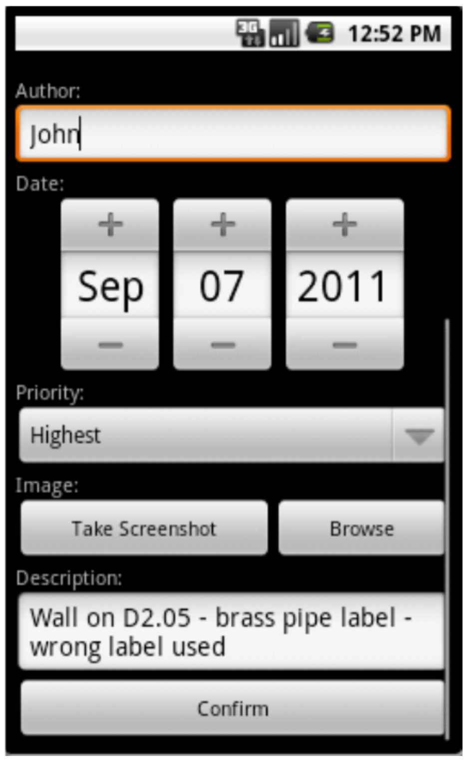

Figure 5: Snag item creation in ARchi saving back to the server-end database

4. TESTING OF ARCHI

The ARchi system has yet to undergo formal user testing, though a number of iterations of heuristic evaluations have been undertaken during the development of the interface to the system. The system has been demonstrated to a number of larger A/E/C companies in New Zealand (Jasmax Architects, Daniel Marshall Architects, Fletcher Challenge Construction, and Hynds Pipes Ltd) to gauge their reaction to the utility of this work. Feedback to date has been overwhelmingly positive and further demonstrations and discussions are planned to identify champions to help progress the development of the infrastructure.

Systematic testing of three aspects of the ARchi system is planned following a second round of refinement of the provided functionality. The three aspects that we will focus the testing upon are: location accuracy in use; heuristic-based usability evaluation; and workflow integration. The location accuracy testing will be vital to ensure confidence in the ability of mobile location-based services such as we propose. Our initial development and demonstrations have identified significant issues with individual location services in particular circumstances (e.g., GPS on built-up sites and inside buildings). The level of granularity which can be guaranteed by the integrating framework of location services needs to be comprehensively evaluated. This will ensure that the processes established around the use of such a service will be appropriate to the required tasks. To date only expert-based heuristic usability tests have been undertaken. These have been useful in identifying major generic usability issues, but do not answer questions about utility of the system with actual users. A formal user testing regime will be set up with one of the A/E/C companies who have expressed interest in ARchi to ensure the interfaces are appropriately specified for their needs. Lastly, the ability to achieve widespread workflow integration needs to be tested to identify other interfaces or APIs which may be required to support the insertion of mobile location-based services into a particular company's software infrastructure. To a large extent this will require further integration testing with the major commercial software tools in use in the A/E/C domain to ensure interoperability can be achieved.

5. CONCLUSIONS AND FUTURE WORK

The proliferation of location-aware smartphones has provided an opportunity to develop more intelligent computerized processes on site. However, to make this a reality requires a sophisticated framework of interoperating services which can deal with the various aspects of on-site processes. The computerization of the snagging process has provided an ideal scenario around which to develop and test such a framework. The work to date identified that the majority of the required functionality can be delivered on consumer-level smartphones on a construction site. This includes provision of a navigable 3D models, data update and retrieval from an Internet-based server, real-time tag identification, and aligned BIM-model rendering on the video stream. However, the accuracy of the model alignment was not of a quality that would be required in a deployable system. This was also true for the location services which were trialed in the projects, where user interaction had to be supported to allow true specification of location in the model. However, industry players were impressed by the potential of the demonstrated location-aware service, indicating likely demand for such applications when these issues can be further resolved. Infrastructure contractors were particularly enthusiastic regarding the information ecosystem's potential to reduce information fragmentation. Infrastructure assets require maintenance over decades by dozens of individuals who generate information in a variety of locations and conditions. For these stakeholders a unified information ecology is considerably more attractive than just computerizing a paper-based process.

The provision of location information is being further investigated in a current project. This is providing a framework which allows any number of location identifying services to be utilized to help refine the user's current location. Depending upon which services are available at any one time they are all polled to provide estimates of the user's location, similar to the approach of Ficco and Russo (2009). By integrating the estimates from each of the location technologies it is expected that a more accurate overall position can be obtained. Future work will also look to generalize the server-based database to ease the process of providing form-based information to services which require location information and 3D data from BIM models. Our work points to the potential of an information ecosystem to affect the fundamental dynamics of design and construction far beyond the simple computerization of its individual manual processes.

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