Specification and procurement of construction products: the case for an agent-based system

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ABSTRACT | This paper presents a justification for APRON (Agent-based Specification and Procurement of Construction Products). This is an ongoing research project aimed at developing an agent-based prototype system for the specification and procurement of construction products. The resulting prototype system will reduce the excessive amount of time spent acquiring information and gaining knowledge about various artifacts. This paper presents a case for deploying agents to assist specifiers and procurers of construction products. It introduces the subject of specification and procurement, highlighting the problems encountered in executing these two tasks. It also described what software agents are and distinguishes them from other closely related paradigms. The paper then presents a case for agents in the selected domain of specification and procurement of construction products. This is followed by a discussion on the features of APRON system. The paper concludes that the specification and procurements of construction products is an appropriate domain for the deployment of software agents.

KEYWORDS | software agents, construction products, specification, procurement, Internet.

1 Introduction

Specification of construction products involves defining constraints that have to be satisfied in a particular artefact. It involves defining the desired attributes, for example, defining aesthetic properties; meeting some regulatory stipulations for example, citing the relevant BS standard; identifying the preferred product manufacturer, for example, stating that the sanitary fittings have to be 'Twyford's Classic'; or even particularising product performance as approved by an expert, for example, delineating the strength of concrete or door fire rating. All these activities will involve making decisions based on information retrieved from heterogeneous, distributed, dynamic, semi-structured and unstructured data and knowledge sources. The components of such sources cannot be predetermined because different people implement them, at different times, using different tools and different techniques.

Procurement encompasses all activities involved in obtaining materials and services and managing their inflow into an organization towards the end user [1]. Traditional procurement in the construction industry comprise several paper-based activities, but over the

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years, the industry made a transition to electronic data management systems starting with EDI (Electronic Data Interchange) based on value-added networks (VAN). The most significant transition was the use of Internet-enabled technologies for document exchange.

Many companies offer some technical information, including aspects relating to construction products, on the Internet [2]. Such use of the Internet has resulted in the emergence of complex relationships. Specification and procurement of construction products now occurs in a distributed computing environment with dynamic relationships among a large number of autonomous service requesters, brokers and providers [3]. Organisations are exposed to several readily accessible alternatives in an increasingly dynamic environment necessitating real-time communication. Consequently, information filtering, information retrieval, evaluations, complex co-ordination tasks and time-based interactions have become inherent in specification and procurement of construction products. When such processes are executed manually, they take up significant time.

These challenges can now be adequately addressed given that the latest developments in information technology model problems quite similar to the fragmentation in the construction industry. Some emerging solutions build on Artificial Intelligence paradigms such as software agents. Agents present a distributed approach to locating, retrieving and integrating information. They, therefore, result in applications that co-operate, co-ordinate and share their information with other applications. This paper is a based on APRON (Agent-based Specification and Procurement of Construction Products); a project that uses an agent-based approach to develop an accurate and efficient way of allowing specifiers and procurers to access and manipulate information on construction products through the Internet.

It is not easy to define the term 'agents.' Nwana [4] provides a number of explanations for this difficulty: it is a common term in every day conversion; it encompasses a broad area; it is a meta-term and researchers in this area have come up with such synonyms as 'bots', 'spiders' and 'crawlers.' Various researchers have defined the term 'agent' in various ways depending on their interests, but some common attributes of agents emerge in all these definitions [5], [6], [7], [8], [9] and [10]. There is a general consensus that software agents exist in an environment. They can sense the conditions in the environment and such senses may affect how they act in future. Software agents are also perceived to be adaptive and capable of learning. They are proactive, exhibiting goal-directed behaviour. The execution of tasks occurs autonomously (without human intervention). It, therefore, suffices to describe agents as systems capable of autonomous, purposeful action in the real world.

There are a number of closely related paradigms that need to be distinguished from agents. Although software agents are programs, many ordinary programs are disqualified from being agents by two basic arguments. Firstly, the output has no effect on what it later senses and, secondly, these ordinary programs lack temporal continuity [7]. Process control systems and software demons exhibit some features of agent-based systems but they lack intelligence and flexibility. Agent technology bears close resemblance to other paradigms such as artificial intelligence, systemics, distributed systems, expert systems, remote programming and object- oriented programming. This is not surprising because such techniques provide the base on which agent technology is built [10], [11], [12], [13] and [24].

The central theme of this paper is discussing the specification and procurement of construction products as an ideal domain for 'agentification.' This section has defined specification and procurement, and also highlighted the problems encountered in executing these two tasks. It also defined software. The next section presents a case for the use of software agents in the selected domain. This is followed by a discussion

on the features of APRON system. The paper ends with a conclusion that the specification and procurements of construction products is an appropriate domain for the deployment of software agents.

2 Review of related work

The fundamental challenge being addressed in the APRON bears close resemblance to the research problem in the GENIAL project: the digital 'anarchy' [2]. The present use of the Internet in construction is characterised by closed markets that cannot utilise each other's services, incompatible applications that cannot interoperate or build upon each other. The approach adopted in the GENIAL project was largely based on the use of standards. The output of the GENIAL project was extended in the eConstruct project [15]. The GENIAL project also resulted in a collaborative project with Loughborough University [16], which focused on extending the discrete product search into a product schedule that could be used perform product comparisons across different suppliers. The APRON project takes this effort to the next level: it utilizes the software agent paradigm to resolve some of the outstanding issues in the initiative to address the digital 'anarchy.' This was also the fundamental subject of the e-bip project, which resulted in a business-to-business Broker Service for the construction tile supply chain [17].

There have been a number of projects focusing on the use of agent to enhance various aspects of design. A few examples are presented here. The ADLIB (Agent-Based Support for the Design of Light Industrial project focussed on developing a multi-agent system (MAS) framework for the representation of the activities and processes involved in the collaborative design of light industrial buildings [18]. In another similar project a multi-agent architecture for the integration of design, manufacturing, and shop floor control activities was developed. This was based on the deployment of cooperating intelligent entities in the sub-domains [19].

Two other closely related agent-based projects are ProcessLink and RAPPID. ProcessLink was a project aimed at providing a technical infrastructure and methodology integrating spatially distributed engineers, designers and their heterogeneous tools [20]. RAPPID (Responsible Agents for Product-Process Integrated Design) aimed at developing a community of agents that help human designers manage product characteristics across different functions and stages in the product life cycle [21]. The agents in this project represent design tools, professionals, design components and characteristics of each component. By trading in a marketplace, these agents resolve conflicts among designers by trading with one another for design constraints, requirements, and manufacturing alternatives.

3 A case for agent-based specification and procurement of construction products

Software agents have a large repertory of attributes as indicated in the preceding section that could potentially extend the performance business information systems developed using conventional techniques such as object-oriented programming [12]. The key features in a software agent's basic anatomy include: autonomy, reactivity and the ability to communicate, plan and set goals, reason about actions and learn. Agents can therefore serve as the basis for developing software solutions that can effectively automate and augment e-commerce processes [22], but this notwithstanding, the use of a powerful abstraction to address a problem is not always justifiable. There are many issues that can be resolved using conventional technologies. The use agent technology in situations that could be adequately addressed without the highlighted added sophisticated inherent in the paradigm would be an overkill solution [23]. This section defines the guideline that was used to identify the specification and procurement of construction products as a relevant problem area for the deployment of an agent-based solution. The themes in this guideline was developed and validated using the

diverse experiences of researchers in agent technology [6], [13], [21], [23] & [24]. These themes have not been outlined in any particular order.

3.1 Handling complex or diverse communication

Rationale: Since agent communication is represented in terms of communicative actions, content language and ontology, the use of software agents results in simpler interfaces, code reuse and analysis or design reuse [23]. This is beneficial in situations where complex or diverse types of communication are required.

Cues: The core activities in an ideal domain for an agent-based solution should be based on human-oriented communication. The problem should also require a solution that is more cognitive than computational in nature. Communication in an ideal domain may be complicated by a need to integrate several heterogeneous, stand-alone applications and legacy systems. If the information required in the domain is only available as several different limited portions, then there may be value in investing in agents.

Evaluating the specification and procurement of construction products: As pointed out earlier, the essence of the specification process is to define an artefact with certain desired attributes. Communication forms a vital part of this activity since it occurs in a naturally distributed and decentralised context. The problem is cognitive and involves a significant amount of intuition. Activities in this domain require tools that can reason with uncertain or incomplete information because some information is only available during the advanced stages of any given project.

Bielawski and Lewand [25] point out that agents should solve problems that cannot be adequately solved by common sense reasoning. Many decisions made in the specification and procurement of construction products are based on the recommendation of an expert. For example, selection of a product that will comprise a structural member will be guided by a structural engineer's stipulations on the strength of materials.

Computing applications complicate communication further. The disciplines involved in the specification of construction products use different programming languages, represent data with different representation languages and models, and operate on different computing platforms. Such differences are visible even in teams within the same company. This can be attributed to the existence of a multitude of computing applications. In the most recent CICA's (Construction Industry Computing Association) listing, there were approximately 1800 solutions specific to or customised for the construction industry listed under the software directory [26].

One very challenging aspect of the problem caused by computing is handling dynamism of software development. It is almost as if as soon as people master the use of one application, software developers come up with a new release. The numerous computing applications used in the specification and procurement of construction products are not immune to this problem. There is a need to make the existing applications future-proof to avoid having to redesign information sources when new software releases become available. Software agents can provide means of making the latest software releases interoperate with legacy systems.

Finally, the different construction product information sources form distinct entities that can be mapped onto problem solving agents. Such distributed data can be processed at the information source with relative ease. All the necessary tasks in these activities can be broken down into standalone processes, which can be delegated to agents.

Clearly, specification and procurement of construction products involves complex and diverse communication and will therefore benefit from the use of software agents.

3.2 A narrow, specific and restricted domain

Rationale: As explained in the previous sub-section, agents simplify communication. For this to be of any benefit to an organisation, the process of simplifying communication should be manageable. It should be possible to restrict the scope to agent tasks, which would not take an individual human being more than a few hours to solve otherwise writing rules for automation becomes a tedious and complicated task.

Cues: The greatest value from using software agents can be realised only when it is possible to precisely articulate the problem.

Evaluating the specification and procurement of construction products: The best way to illustrate how the specification and procurement of construction products satisfies this requirement is to actually model an agent in this domain. A simple valve specification agent has been described Table 1.

Table 1. Usage scenario

Scenario outline: A valve specification agent is required to match designer's requirements and the manufacturer's brochure. The building codes and the client's brief govern the choice, expense and type of product the designer is allowed to use. Here we consider an agent, within a designer's office, to which the designer can give product requirements. The agent then explores the various product possibilities, within the scope of the Client's brief and the building codes. The agent asks the designer to decide which options to pick generating a detailed specification for the product.

Valve Specification Agent

Identity: The agent is identified by the task of establishing valve attributes and associating them with a designer's requirements.

Roles: Valve requirements extraction and detailed valve specification generation.

Interactions with environment:

Sensory input: The designer initiates the process by selecting a desired category of attributes, for example, Specific-Gravity, Flow, Temperature, Outlet_Pressure and Inlet_Pressure. He/ she then proceeds to specify a value for the selected attributes, for example, 23.70 psi and 27.90 psi Outlet_Pressure and Inlet_Pressure respectively.

Acquaintances: In this scenario it has been assumed that the agent interacts with only one other agent, the Valves' Catalogue agent.

Resource ownership and access: The designer has read-only access to Manufacturer's valves brochures to enable the electronic viewing of product attributes.

Actions: (Communicate) Get Valve Attribute Category from the designer (for example, Specific-Gravity, Flow, Temperature, Outlet_Pressure and Inlet_Pressure et cetera).
(External) Gather information on options from Manufacturers' brochures.
(Internal) Evaluate the options and decide on the best selection based on the specified constraints.
(Communicate) Suggest options to the designer.
(Communicate) Get choice from designer.
(Communicate) Get a desired value for the selected valve attribute where applicable.
(External) Gather information on various options from Manufacturer's brochures.
(Internal) Evaluate the options and decide on the best selection based on the specified constraints.
(Communicate) Suggest options to the designer.
(Communicate) Get choice from designer.
(Internal) Construct detailed specification for the product.

Mental state and behaviour:

Purpose: The agent's goal is to extract valve performance requirements from a designer and to turn this into detailed product specification by suggesting alternatives to the user based on constraints imposed but the designer and product availability as documented in the Manufacturer's valve brochure. Once the designer makes the choice the agent generates a detailed product specification that can be used for bidding.

Behaviour: The agent is not able to procure the specified valve without the designer first confirming a choice.

Knowledge and beliefs:

- How to generate specifications based on a designer's requirements.
- How to access and use information from a Manufacturer's product brochure.

The information presented in Table 1 illustrates how the various aspects of specification and procurement of construction products can be readily broken down into simple agent tasks. It is evident that the specification and procurement of construction products as an application domain is narrow, specific and restricted enough to allow for easy deployment of agents.

3.3 Inability to specify system behaviour on a case-by-case basis

Rationale: If high levels of flexibility and adaptiveness were deemed as important attributes of a required system, then an agent-based approach would be worth considering. It has been established that agents-based systems are highly modular enabling isolated development of individual agents and/or their organisational groupings [27]. Such components can therefore be added in an incremental manner to create the whole system.

Cues: An ideal domain for an agent-based solution should require a system that will exist in a relatively unknown environment in which it is impossible to foresee all future situations. Agent-based systems can also be used in this context to model systems whose performances gracefully degrade as uncertainty increases. Domains that present several routes to attaining a goal depending on the prevailing circumstances are also ideal.

Evaluating the specification and procurement of construction products: The construction industry exhibits a number of the challenges that can be handled by agent-based systems. The first challenge emanates from shift to executing construction-related tasks on the Internet, an open system with a dynamic structure. This has resulted in the need to develop open, distributed, systems with heterogeneous and flexible architectures. The use of software agents shift the focus from developing systems with a particular configuration to the inclusion of flexible (objects) agents 'that can be swapped in and out as the entities they represent are shuffled around' [28]. Such systems can adapt to changes in the context of operations and changes in needs.

A second challenge emanates from the way construction information evolves from being very sketch at the inception of any projection to detailed drawings that are issued during execution. At the start of a construction project, it is not possible to have a perfect view of what lies ahead. The performance of the whole process 'gracefully degrades with increase in uncertainty' and variations in product specifications are inevitable. An agent-based system would enable the various parties involved to easily expand or modify their information systems as more information becomes available.

The final challenge in this context revolves around the fact that construction professionals generally have to choose from myriad options to choose from, each of which may be appropriate depending on the usage scenario. It therefore becomes impossible to adequately specify system behaviour on case-by-case basis. Because the behaviour of a software agent is goal directed, it becomes easier to adapt to the prevailing circumstances and select the best route to achieve the goal.

3.4 Handling negotiation, co-operation and competition among different entities

Rationale: Agents generally exist in the context of multi-agent communities and their behaviour derives from the interaction among constituent agents [29].

Cues: Problems that require solutions that can handle concurrent execution of multiple tasks with conflicting goals are ideal candidates for agent-based solutions. Other qualifying features include the existence of multiple stakeholders with different interests, and the existence of problems that are both too complex for a monolithic solution and too difficult to decompose into independent sub-problems.

Evaluating the specification and procurement of construction products: Specification of construction products is executed as a multi-disciplinary operation meaning that in any project, there are different points of view. The various disciplines involved have compartmentalised themselves over time. Each of them has evolved a unique view of the world and developed special terminologies. Each discipline pursues built-in goals, which may conflict with the global goals of the design; for example, aesthetics goals may conflict with keeping the budget low. Due to focussed expertise, certain solutions are only true ceteris paribus (all things held constant). When one person makes changes, all the other disciplines may have to pursue new goals.

There are a number of stakeholders: the client wants a habitable space, the regulatory bodies demand compliance with stipulated codes and by-laws and the contracted companies seek to maximise their profits. In extreme situations parties quite remote to the contract may feature. For example, environmentalists and people concerned with maintaining a certain look and feel for heritage or cultural reasons.

There are also other issues that can be adequately addressed using software agents. Disciplinary design is presented in big modules hiding details that may be necessary for integration [30]. Further complexities arise from multifaceted interactions; multiple disciplines may focus on one parameter simultaneously. In addition to these problems, the counter-intuitive behaviour of many designers needs to be modelled. Intuition is ineffective or adverse when constraints become active and comprehensive studies are needed to integrate the problem. Through modularity and abstraction, agents offer means of dealing such complexities.

3.5 Need for autonomous execution

Rationale: An ideal application domain must demonstrate a need for the advanced level of autonomy inherent in agent-based systems [24].

Cues: The deployment of agents in a given domain makes sense only when there is a need for a system that is capable of acting on behalf of a user.

Evaluating the specification and procurement of construction products: The publicly indexable Web contained an estimated 800 million pages as at February 1999, encompassing about 15 terabytes of information or about 6 terabytes of text after removing HTML tags, comments and extra whitespace [31]. Specification of construction products requires searching, querying and filtering out 'noise' from this magnanimous library. Even within construction industry-specific Web sites there are numerous portals. By early 1999, there were 150 to 200 Internet companies focusing on construction industry-specific e-commerce, with an estimated investment exceeding $1billion or about £671 million [32]. Overwhelmed by 'information overload' [33], specifiers require agents to automate the execution of some tasks.

4 Discussion

The five basic arguments presented in the preceding section demonstrate that there is a major scope for agent-based specification in the specification and procurement of construction products. There is, however, a need to further demonstrate the commercial viability of the approach, particularly because agent-based e-commerce applications (unlike other application domains such as distributed, networked applications) have only had limited success [34]. The slow uptake can easily be attributed to the fact that e-commerce is a very new domain with supporting technologies maturing gradually. Naturally, commercial investment will initially be minimal and a number of cultural hurdles will have to be overcome. Developers in agent technology will have to actively crusade for enthusiasm from potential investors. The arguments developed in the preceding section can be used to demonstrate that agent agent-based solution

can provide a competitive advantage in e-commerce in a number of ways as outlined below:

- Agent-based solution result in a new and innovative way of handling problems and therefore, make a difference to the way the organisation operates;
- Agent-based solutions can automate repetitive functions and therefore, free employees from performing routine tasks - this increases productivity and profits;
- Agents can propagate and proliferate knowledge, and therefore make the process of handling knowledge more efficient by (for example, when knowledge from previous projects is wrapped using an agent, it becomes easy to preserve and reuse it);
- Domains that have multi-player or multi-criteria decision-making can ensure consistency through the use of software agents.

Within the context of specification and procurement of construction products, the value of deploying an agent-based solution becomes apparent when problems emanating from fragmentation prevent the free-flow of information. Figure 1 provides a three-dimensional illustration of this fragmentation.

It is clear from the diagram that requisite information is physically dispersed among the various professions and further distributed across the various construction phases. Such problems have been compounded on the electronic networks through, for example, the use of different computing applications and the displaying of information in heterogeneous formats. This has resulted in a need to facilitate communication across different applications. Although there have been tremendous strides in the area of application integration, there is still significant scope for further improvements [35]. The traditional object-oriented paradigms are not capable of adequately addressing these problems. Schulte and Altman, [35] describe the two aspects of complicated nature Application-to-Application integration. The simpler aspect of this problem emanates from the fact that codes within an application program have often been modified several times. The more complex aspect problem is the 'inter-application spaghetti' that links programs and databases across an enterprise and its e-business networks as depicted in Figure 2. There is a gap that can be filled with software agents. The agents' ability to provide autonomous integration of legacy data can be used to provide interfaces to the depicted complex mesh. APRON agents will use this capability to support the specification and procurement of construction products.

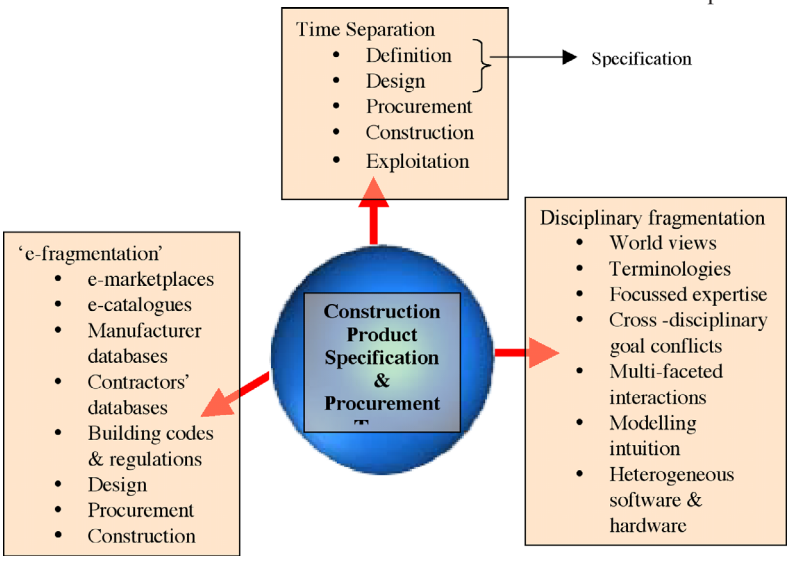
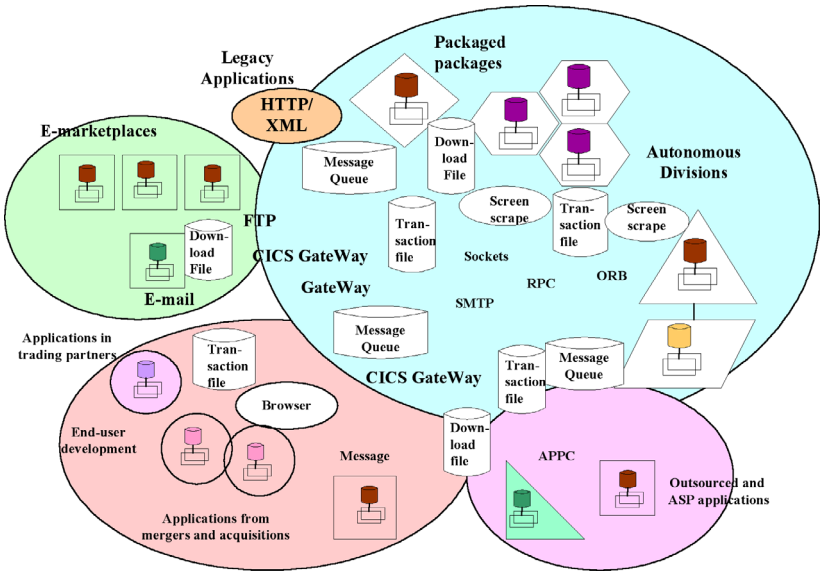


Figure 1. Dimensions of Fragmentation



Key:
APPC = Advanced Program-to-Program Communications
ASP = Application service provider
CICS = Customer Information Control System
FTP = File Transfer Protocol
HTTP = Hypertext Transport Protocol
RPC = Remote procedure call
SMTP = Simple mail transfer protocol
XML = Extensible Markup Language

Source:
LeVasseur, 2001

Figure 2. Application Integration Spaghetti

It is easy to assume that the e-business sector is adopting standards to address the heterogeneity problem. Researchers who have adopted this point of view may believe that the potential role of software agents as diminished by standards. This is, however very far from reality. Standards cannot eliminate the application integration role played by agents in collating information from diverse sources. McCoy and Thompson [36] present three main arguments affirming this view. Firstly, none of the existing standards is mature enough (the standards lack a critical mass). Secondly, while it is possible that some robust standards will eventually reach maturity, they still face the challenge of scope: adopting one set of standards generally excludes another community using different standards. Finally, heterogeneity is 'a moving target' with new strains emerging all the time. The APRON prototype system enables specifiers and procurers of construction products to easily access and manipulate information from heterogeneous sources.

There is an obvious correlation between APRON and search engines. However, a critical review of the former would reveal that its functionality is more sophisticated and yields more accurate and precise results compared to traditional search engines. The superiority of the APRON search functionality manifests itself in three basic ways. Firstly, search engines bring back documents while APRON agents will bring back specific information contained in the documents. Secondly, the response from typing in a keyword in a search engine can potentially result in a magnanimous quantity of replies while APRON narrows the search based on a more intimate knowledge of the user. Finally, search engines often have directory-like services, which are assembled by human indexers through a long, tedious task. Such processes are not as dynamic as the Web and often result in incomplete indexes. The APRON agents execute their task dynamically. APRON provides agents that can provide focussed information to support a specific information analysis task.

Because agents are capable of several of advanced things (such as making informed decisions; learning and adapting over time; communicating with other agents, and integration with legacy systems), their use in this context would complement the existing technologies

in the quest to integrate the fragmented team. The existing e-commerce applications for the construction industry have made a significant contribution through the deployment of technologies that increase the volume of information available electronically. The inclusion of an agent-based component would improve the quality of such information through automated filtering. Agent services such as brokering, translation and coordination can be used to save the time spent in gathering information. The agents handle the various dimensions of fragmentation and increase the knowledgebase. These can add value to the operations involved in the specification and procurement of construction products.

An APRON (agent-based specification and procurement system) prototype has been implemented based on this premise. The APRON prototype was modelled using the established mediation/wrapper methodology, that was used in, for example, the InfoSleuth prototype [37] and the SEEK prototype [38]. In this approach, the developed solution constitutes a software middle layer between the semi-structured repositories of construction products and the end-user applications utilised in specification and procurement. This is depicted in Figure 3.

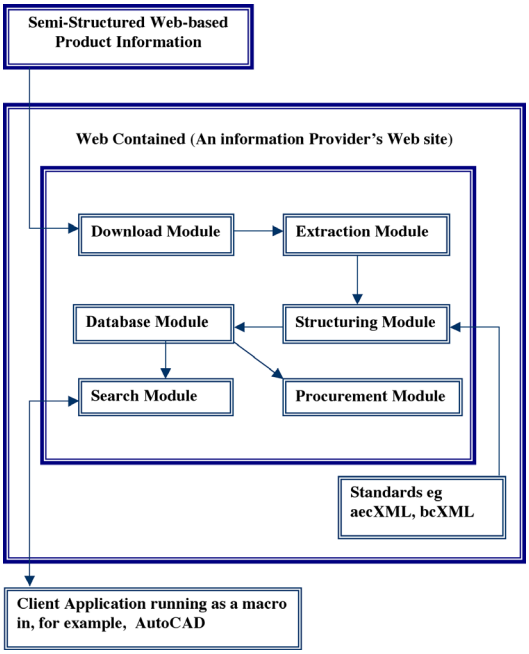


Figure 3. The APRON Architecture

There are three distinct, intercommunicating layers. The construction product manufacturers are at the top level in the architecture. Manufacturers display details of the various product offerings as semi-structured data on the Internet. The kernel of the architecture is the e-marketplace of an Information Provider, who uses the Internet to ensure that requisite project information is available to all the key players in the construction project supply chain. This e-marketplace hosts the APRON solution, which comprises the Download, Extraction, Structuring, Database, Search and Procurement Modules. The e-marketplace also holds a repository of relevant standards that can be used as XML schemas for structuring the extracted information. The final layer comprises the end-user firms in the specification and procurement of construction products. The focus in these firms is providing an automated interface to the computing applications used by specifiers and procurers. A client application has been deployed to allow such end-users to communicate with the APRON Web Service.

The APRON system provides a link between the Web site holding product information and the applications used in the specification and procurement of construction products. The Download Module maintains real-time access with these Web sites. Text is then extracted from the downloaded file, and using previously defined XML schemas, structured into a context-specific format. Industry standards, such as IFCXML and bcXML, can be easily adopted and used to create an XML template for structuring the extracted information. The APRON system also stores the relevant information in a database. Information for the specification and procurement of construction products is obtained from this database. Specifically, APRON, provides a Web-based search engine, which can be used to execute context-specific queries for construction products. The APRON solution also

offers a framework for automating the procurement of specified products. The Procurement Module has two types of agents: a buyer agent and a seller agent representing product procurers and product sellers respectively. The two agents exchange requisite information and automate the transactions involved in the procurement of construction products.

5 Conclusion and Summary

The paper introduced the selected application domain, the specification and procurement of construction products, and highlighted the problems inherent in these activities. Agent technology is identified as a potential solution to these problems. The working definition for software agents has been derived from their well-known attributes and the distinction of agent paradigm from other closely related technologies. An overview of closely related work has been presented in the paper. The main section of the paper is devoted to defining the applicability guideline that was used to establish that the deployment of agents in the specification and procurement of construction products would not be an overkill solution. These covered the need to handle diverse or complex communication, the ability to restrict the scope of application, the need for flexibility and adaptiveness, concurrently handling multiple goals that could possibly conflict and the need for autonomous execution.

A major issue that emerged in the paper is the need to present the proposed agent-based solution as a commercially viable investment with benefits that can be expressed using business metrics such as freeing employees from routine tasks, preserving knowledge and ensuring consistency in multi-player or multi-criteria decision making. It is important to understand that the APRON prototype is not a replacement to existing technologies – it underpins them and provides additional functionalities based on agent sophistication. This has been demonstrated in the paper through a description of the APRON architecture.

The specification and procurement of construction products occurs in a collaborative but fragmented environment. The use of agents is justified by the existence of distributed teams. Information, which is very critical to the successful execution of the project by such teams, is multi-dimensional by nature. The key questions in identifying the different dimensions of information are: who needs information, what information is needed and in which format; who possesses the information, where and in what format does the information exist; and finally when, where and how information exchange occurs. A critical analysis of these themes has established that the information required for the specification and procurement of construction products is distributed, dynamic and semantically discrete. The paper is strewn with reference to literature affirming the view that human agents are overwhelmed by the workload involved in addressing all these dimensions simultaneously.

Though the existing technologies (particularly ones based on object-oriented paradigm) have significantly addressed some of the problems related to the distributed and dynamic nature of information, collaboration requirements are advancing to a higher level. There is a growing need for sophisticated applications that can handle all the possible dimensions of information; there is a need for new approaches that will enable efficient retrieval and manipulation of information during the specification and procurement of construction products. Agent-based approaches appear to offer considerable potential and this paper has described in detail why the selected domain is a suitable candidate for 'agentification.' Implementation and evaluation of the resulting prototype are expected to further confirm this and will be the subject of a future paper.

The suitability of the specification and procurement of construction products for the deployment of an agent-based approach does not guarantee that a prototype such as APRON would be an immediate success in a commercial context. This is largely because software

agents only address part of the problem of integrating disparate pieces of information. Software agents' contribution to a system is a sophisticated level of flexibility and adaptiviness derived from their basic anatomy as autonomous, proactive and goal-directed entities. There are a number of issued that will have to be resolved using different technologies for the entire process of using Internet-enabled systems to support the specification and procurement of construction products to work efficiently. In this regard, critical research issues that need to be addressed include the development of intelligent product libraries that agents can search, the integration of heterogeneous information sources and formats, the development of appropriate interoperability standards and the degree of autonomy agents are allowed to have by their owners in making transactions.

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