A process-oriented approach to supporting Off-site Manufacture in construction projects

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Abstract

It is well-known that the use of off-site manufacture (OSM) techniques can assist in timely completion of a construction project though the utilisation of such techniques may have other disadvantages. Currently, OSM uptake within the Australian construction industry is limited. To successfully incorporate OSM practices within a construction project, it is crucial to understand the impact of OSM adoption on the processes used during a construction project. This paper presents how a systematic process-oriented approach may be able to support OSM utilisation within a construction project. Process modelling, analysis and automation techniques which are well-known within the Business Process Management (BPM) discipline have been applied to develop a collection of construction process models that represent the end-to-end generic construction value chain. The construction value chain enables researchers to identify key activities, resources, data, and stakeholders involved in construction processes in each defined construction phase. The collection of construction process models is then used as a basis for identification of potential OSM intervention points in collaboration with domain experts from the Australian construction industry. This ensures that the resulting changes reflect the needs of various stakeholders within the construction industry and have relevance in practice. Based on the input from the domain experts, these process models are further refined and operational requirements are taken into account to develop a prototype process automation (workflow) system that can support and coordinate OSM-related process activities. The resulting workflow system also has the potential to integrate with other IT solutions used within the construction industry (e.g., BIM, Acconex). As such, the paper illustrates the role that process-oriented thinking can play in assisting OSM adoption within the industry.

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1. Introduction

Effective and efficient management of construction processes is crucial in driving successful execution of a construction project. One way to increase the productivity within the construction sector is to include a greater percentage of off-site manufacture into each project. However, to successfully incorporate off-site manufacture (OSM) practices within a construction project, it is crucial to understand the impact of OSM adoption procurement on the construction management processes. In other words, a different assessment has to be made as to which activities need be changed or adjusted for an OSM procurement delivery method. These changes include OSM products information availability, appropriate timeframes for OSM-related decisions, and how and when these changes should be incorporated in the construction management process (Rezgui & Cooper, 1998).

Business process management (BPM) provides organisations with the ability to save money and time by systematically documenting, managing, automating and optimising their business processes (Weske, 2007). This is achieved by promoting a process-centric view of an organisation through end-to-end management of business processes. Progressively, the construction industry has started looking at its processes in order to gain standardisation as well as process efficiencies (Kagioglou, Cooper, & Aouad, 1999; Motzko, 2008). Sophisticated procedures exist in most areas in order to comply with legislative requirements including (but not restricted to) procurement processes, building processes and healthy, safety and environment management processes. These construction management processes have improved as the opportunity arises, especially as new technologies are accepted. Substantiated by research in real-time management of construction processes, Motzko (2008) argues for the implementation and stabilisation of strict processes within the construction industry in order to increase process optimisation and undertake the process of continual improvement of processes. Generally speaking, a clear place to start assessing the optimisation of process within the construction industry would be to look at current processes and the use of them. In addition, with the introduction of lean management concepts in the construction industry, BPM is clearly an important contributing factor.

This paper presents how a systematic process-oriented approach may be able to support OSM utilisation within a construction project. Process modelling, analysis and automation techniques which are well-known within the BPM discipline have been applied to develop a collection of construction process models that represent the end-to-end generic construction value chain (Kanjanabootra, Wynn, Ouyang, Kenley, & Harfield, 2012; Kenley, Kanjanabootra, Ouyang, & Wynn, 2012). The collection of construction process models is then used as a basis for identification of potential OSM intervention points in collaboration with domain experts from the Australian construction industry. Based on the input from the domain experts, these process models are further refined and operational requirements are taken into account to develop a prototype process automation (workflow) system that can support and coordinate OSM-related construction management process activities.

2.   Research Approach

The research approach adopted in this study is in line with the Design Science methodology in information systems research (Hevner, March, Park, & Ram, 2004). Also, it is similar in nature to the previous research that was conducted involving application of process-oriented approach to film productions (Ouyang, La Rosa, ter Hofstede, Dumas, & Shortland, 2008) and to the scheduling in surgical care processes (Ouyang et al., 2011). Successful adoptions of the Design Science methodology in previous research have further assured us to apply the same methodology in this study.

There are seven guidelines for the Design Science methodology as reported in (Hevner, et al., 2004). According to Guideline 1 (Design as an Artefact), the project started with the development of construction process models and the design of a purposeful IT artefact – a prototype workflow system that can support and coordinate OSM-related process activities within a construction project. Moving to Guideline 2 (Problem Relevance), this artefact is innovative and purposeful to the domain of construction management based on the fact that process management in the building industry is considered important but not sufficiently addressed. Guideline 3 is concerned with Design Evaluation. Through interviews with stakeholders, on-site observations, and literature review, access to domain expertise was available for the design and development of our artefact as well as validation of the design to a certain extent. Our research aims to contribute to the field of construction management with regard to Guideline 4 (Research Contributions), and due to the adoption of a well-established theory (i.e. process-oriented lifecycle approach) we consider our research outcome as addressing Guideline 5 (Research Rigor). The research process though is not finished and the resulting artefact requires continuous questioning, revision, and extension. This indicates that the design of our artefact is a Search Process as in Guideline 6. Finally, following Guideline 7 (Communication of Research), our research process aims to expose the research to both the IT community, among others through publications, and to the building industry, which includes the Sustainable Built Environment National Research Centre (SBEnrc) in Australia.

3.   Analysing/Discovering Construction Processes

When an organisation takes on a BPM initiative, it goes through the different phases of the BPM lifecycle (see Figure 1). There are typically a number of distinct and iterative phases; namely, design, implementation, enactment and diagnosis (Weske, 2007). During the design phase, the process requirements are gathered from the stakeholders and an initial set of business process models are designed based on the requirements. In the implementation phase, the processes are further refined and operational requirements are taken into account to enable implementation as a software system (i.e. executable workflows with data and resource perspective). During the process enactment phase, these workflows are then executed to provide automated support for the business processes using workflow systems or process-aware information systems. During the diagnosis phase, the executed processes are carefully examined and the performance of these processes is monitored so that process improvement activities can be carried out, which in turn, leads back to the design phase (often known as process redesign).
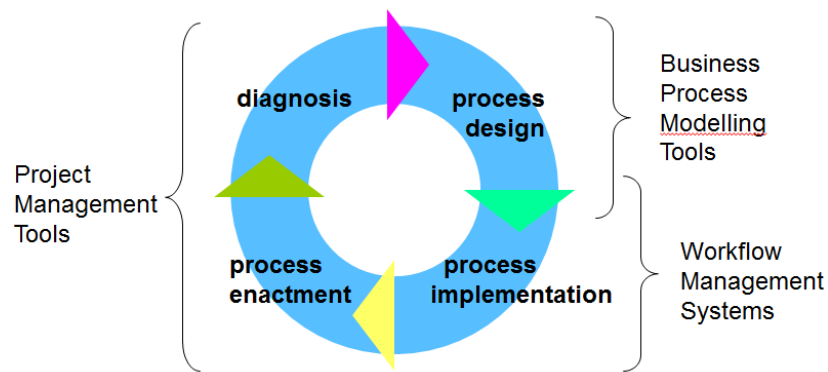
Figure 1 Business Process Management lifecycle (adopted from (Dumas, van der Aalst, & ter Hofstede, 2005))

Construction process modelling has been studied before. Al-Bazi et al (2010) developed a process model of concrete production crew allocation to manage pre-cast concrete production process (Al-Bazi, Dawood, & Dean, 2010). A number of IT related applications were developed to support construction process in a specific stage of the construction such as the design or the production (Baldwin, Poon, Shen, Austin, & Wong, 2009; Benedict & David, 2012; Bouchlaghem, Shang, Whyte, & Ganah, 2005; Forsman et al., 2012). BIM technology has been proposed to be used in off-site manufacturing (Brodetskaia, Sacks, & Shapira, 2011; Frawley, 2011; Sacks, Radosavljevic, & Barak, 2010). However, BIM technology by itself is not a one-stop service that can enable OSM in a construction project. The construction process modelling mentioned in the literature cannot be applied directly for OSM adoption. Many applications focused on only a specific stage of the construction process and they typically do not cover all relevant stakeholders involved in the construction process. In (Kanjanabootra, et al., 2012; Kenley, et al., 2012), we presented our work on how construction process models with OSM-related activities are created using domain knowledge from different stakeholders.

We developed a generic six-phase construction value chain model described in Business Process Modelling Notation (BPMN) notation as part of the process design phase. The six phases where OSM intervention points could be incorporated are: Arrange Project Team, Develop Detail Design, Prepare Tenders, Tendering Award Contract, Build, Hand Over and Operation. Detailed BPMN models describing the individual phases can be found in (Kenley, et al., 2012). These simple phase distinctions were made with the understanding that any generic model is only a representation of a very complex set of processes taking into account a variety of stakeholder perspectives. The development of this value chain model is grounded in a research team with professional industry experience combined with a review of the literature and analysis of industry reports and policies. At each point appropriate for OSM consideration of capability and capacity is indicated by reference to an OSM Checklist. The entire construction process BPMN model serves as a baseline model for the development of a prototype workflow application, which is the focus of this paper.

4.   Construction Process Workflow

4.1   The YAWL language

While the BPMN notation is an appropriate modeling technique to represent high level processes, the notation is not ideally suited to model executable workflows (Wohed, van der Aalst, Dumas, ter Hofstede, & Russell, 2006). The Yet Another Workflow Language (YAWL) notation can be used to model formal and executable business processes (van der Aalst & ter Hofstede, 2005). The YAWL language is supported by the open-source workflow environment developed using the service-oriented architecture (van der Aalst & ter Hofstede, 2005). Because of its formal foundation and its support for design, enactment, implementation of complex executable processes, the YAWL language has been chosen as the modelling language for executable workflows and the YAWL environment as the development framework within our research project.

A YAWL process model consists of tasks and conditions (see Figure 2). Each process model starts with a unique input condition and a unique output condition, which signal the start and the end of the process, respectively. There are atomic tasks and composite tasks. Atomic tasks correspond to atomic actions, i.e. actions that are either performed by a user or by a software application. Each composite task refers to a sub-process that contains its expansion. In addition to tasks and conditions, there are routing constructs (those split and
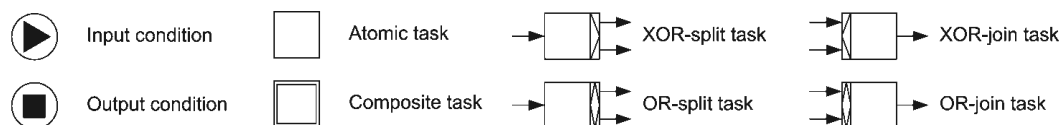
Figure 2 A subset of the YAWL modelling notation

join tasks) used for modelling the divergence and convergence of the flows between tasks. The AND-split and -join tasks capture parallel execution of tasks. The XOR-split and -join tasks capture an exclusive choice among a number of alternative task executions, while the OR-split and -join tasks capture inclusive choices.

4.2   YAWL Workflow for the Construction Process

An overview of the phases in a typical construction project is captured by top level YAWL model (making use of composite tasks to represent phases) as shown in Figure 3. In this paper, we focus on demonstrating how the various activities within the "Arrange Project Team" phase can be supported by a workflow system.
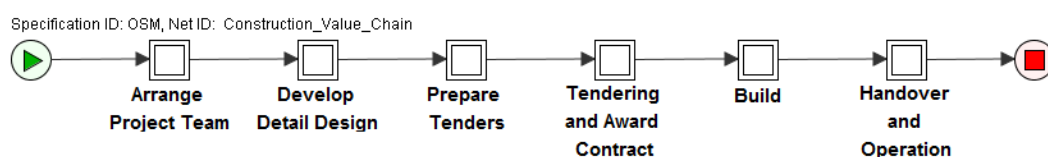
Figure 3 Construction Value Chain YAWL Model

A workflow model captures three different perspectives: the control flow perspective, the data perspective and the resource perspective. The **control flow perspective** of a workflow

is concerned with the order in which tasks within a process is executed. Most of the tasks within the "Arrange Project Team" workflow follow a sequential order (see **Error! Reference source not found.**). There are also decision points in the model, for instance, an XOR-split following the task "Review Business Plan" represents a decision to go forward a path (one of approve, revise or reject) based on the outcome of the review task. This decision by the user is captured using a data variable that is selected from a dropdown list (see **Error! Reference**
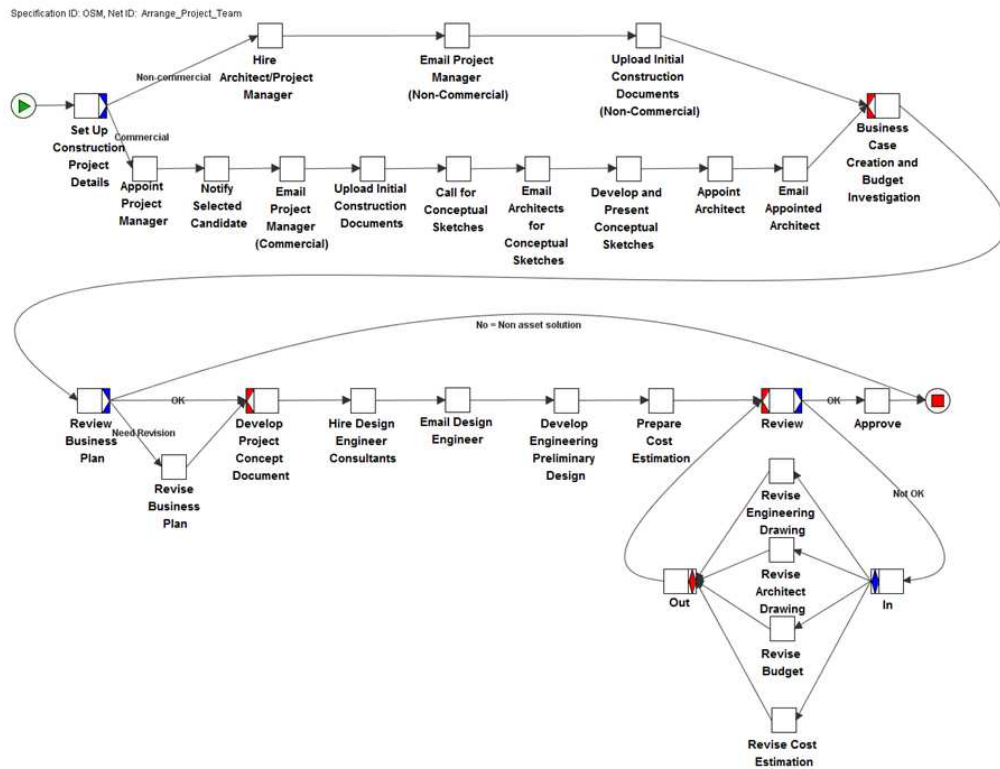
Figure 4 Appoint Project Team YAWL Models

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This is representative of **the data perspective** which captures information being passed between various tasks. The YAWL workflow environment supports a sophisticated data handling mechanism making use of XML data types.

The **resource perspective** of a workflow is concerned with capturing the "actor" who is responsible for carrying out tasks. This actor/resource can be a human, a machine, an IT system or the workflow environment itself. In the "Arrange Project Team" process, there are a number of different actors involved. Most are human resources who have roles of Architect, Client, Engineer, Project Manager and Quality Surveyor (i.e., role-based resource allocation mechanism is used), some are modelled using web services (e.g., email, file upload). The YAWL environment allows many sophisticated resource allocation strategies.

Figure 5 XOR Decision making example

In the "Arrange Project Team" workflow, the "Four-eyes principle" is used to specify that the person who reviews the business plan cannot be the same person who created the business case and the budget. The "Chain Execution strategy" is used to specify that the person who completes the "Appoint Project Manager" task is assigned to carry out the next task of notifying the selected candidate.

A number of tasks within the "Arrange Project Team" workflow have been identified as having **OSM implications**. The OSM-related tasks include: Business Case Creation and Budget Investigation, Develop Project Concept Document, Develop Engineering Preliminary Design, Prepare Cost Estimation, Review, Revise Engineering Drawing, Revise Architect Drawing, Revise Budget, Revise Cost Estimation and Approve. For these OSM-related tasks, notifications/alerts are available to download a checklist provided for OSM. This
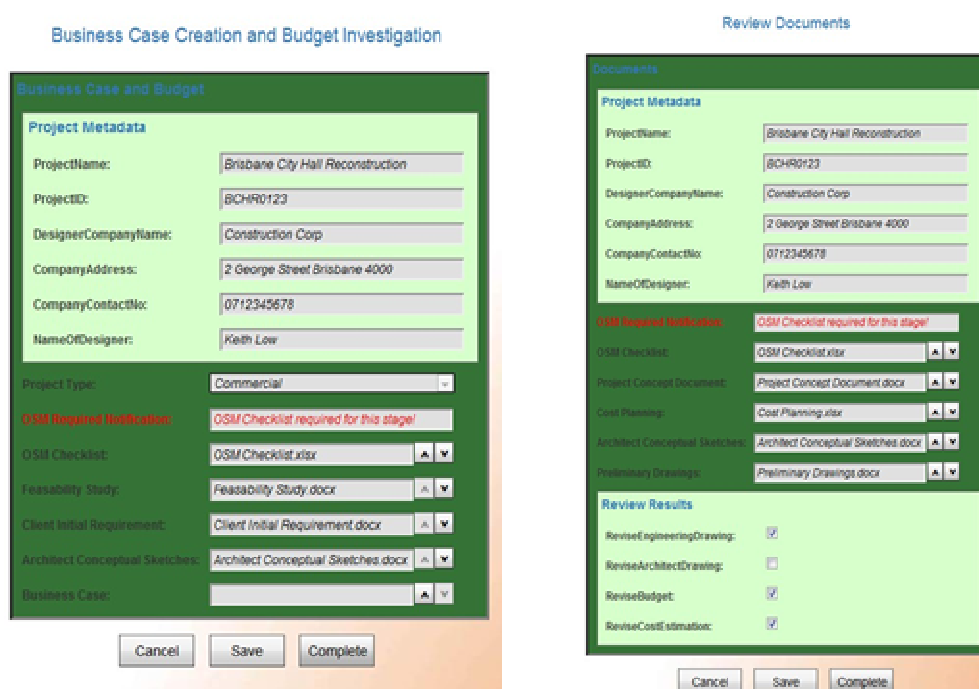
Figure 6 Tasks that have been identified as having OSM Implications

checklist can then be re-uploaded after making modifications as shown in Figure 6.

4.3   Process Enactment with the YAWL environment

In this section, we illustrate how the resulting workflow for the "Arrange Project Team" workflow is enacted and supported within the YAWL environment.

4.3.1   Resource Service

Firstly, the workflow is uploaded to the YAWL environment and a case for the new project can be started within the resource service. After a new case is started by the client, web forms are available to fill in the project details (as seen in **Error! Reference source not found.**). The YAWL environment provides automatically generated web forms that can be customised (as seen in **Error! Reference source not found.**). Further customisation is possible (e.g., by adding the logo of the organisation etc.) using the feature of custom forms.

Figure 7 YAWL's work item queue

Figure 8 Upload initial construction documents page
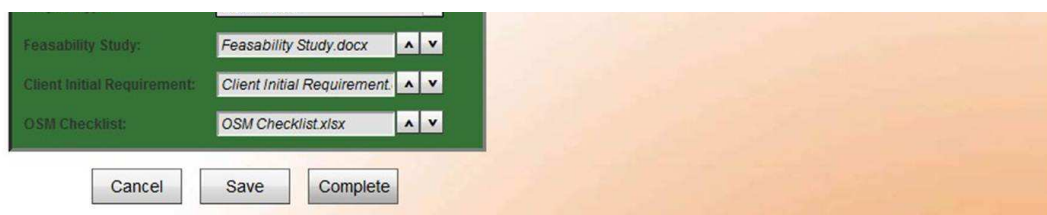
Figure 9 Appoint project manager custom form

Figure 10 Project manager selection criteria custom form

Three custom forms were developed for the "Arrange Project Team" workflow using the

colour scheme of SBEnrc. Figure 9 shows the form for the "Appoint Project Manager" task where the scores for the shortlisted applicants can be calculated (Figure 10) and recorded using the "Edit Score" function. The candidate with the highest score is then selected for appointment. These custom forms were used to capture the user interactions with the YAWL environment.

4.3.2 Mail, Document Upload, and Monitoring Services

In addition to user tasks, the YAWL environment enables third-party web services to be automatically invoked through automatable YAWL tasks by setting up the links within the YAWL workflow editor. Another custom webform is created to capture the necessary details to notify the selected Project Manager applicant of the appointment (see Figure 11). When the form is submitted, the **mail custom service** is automatically invoked to send out the email.

Figure 11 Notify (by email) selected applicant custom form

Another custom functionality that was used within the workflow is the **document upload service** which supports the storage and passing of documents between tasks. The service enables uploading, transfer and downloading of documents such as OSM Checklist, Architect Conceptual Sketches, Business Case, and many more (see **Error! Reference source not found.** and Figure 8).

All the cases running within the YAWL environment can be closely monitored by an administrator using the **workflow monitoring service**. Figure 12 shows the sample screen for monitoring activities carried out within the construction workflow projects.

There are also many other capabilities of the YAWL environment that can be useful for construction workflows. They include the use of timer tasks to indicate deadlines and
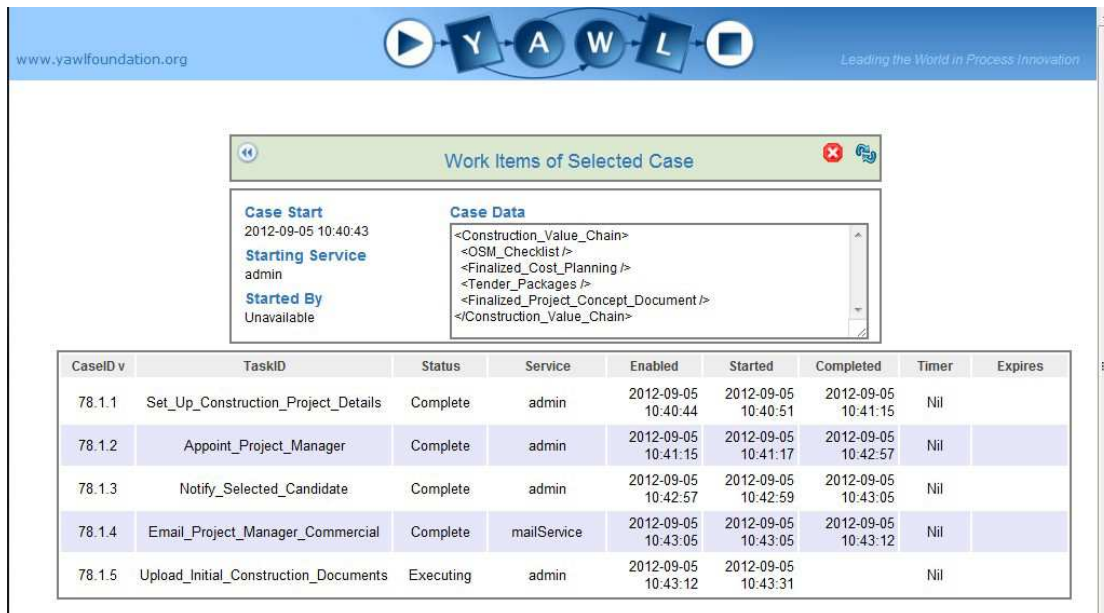
reminders, the use of digital signature service to fast track approval in a safe and secure

Figure 12 Monitoring services page

manner, the use of SMS services for employees to complete tasks on a mobile device, etc.

5.   Conclusion and Future Work

This paper presents how a systematic process-oriented approach may be able to support OSM utilisation within a construction project. Several interviews with domain experts from the Australian construction industry enable researchers to develop a collection of construction process models and a detailed OSM checklist which are then used as a basis for development of a prototype process automation system in the YAWL environment to illustrate how OSM-related process activities can be supported and coordinated. As such, the paper illustrates the role that process-oriented thinking in the form of process modelling, analysis and automation could potentially play in assisting OSM adoption within the industry.

Due to the project's interdisciplinary scope, further evaluation can be approached from two different angles. On the one hand, as researchers in the field of BPM (more broadly the domain of information systems), we plan to apply the observational method where our artefact is evaluated through demonstrations to the stakeholders. On the other hand, in the domain of construction management, our findings are expected to bring process innovation to the building industry. To this end, alternative evaluation strategies such as Design Experiments (Brown, 1992) or Design-based Research (Barab & Squire, 2004) can be applied to evaluate the significance of the innovation for the building industry.

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