# ACTION RESEARCH PROJECT

मानकः पथप्रदर्शकः
Bureau of Indian Standards

# Architecture Frameworks for Complex systems - General Concepts and Guidelines for drafting standards

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# 1 Introduction

BIS has published IS 12:2005 Guide for Drafting and Presentation of Indian Standards. The standard provides detailed guidelines for

a) drafting Indian standards and
b) adopting international standards as Indian standards

IS 12 is suitable for drafting product standards and test methods etc. however, it does not clearly specify how to draft other types of standards, especially frameworks for software systems such as Reference Models, reference architectures etc. as the reference architectures and such frameworks are described in a different way.

*This action research explores the international standards and literatures available around systems architecting and provides a brief overview of general concepts in the field of architecture descriptions and provides a brief guideline for drafting standards on Architecture Frameworks for complex systems.*

## 1.1 Why architectures?

The human innovations and technological disruptions in the past few decades increased the complexity of man-made systems to an unprecedented level. While it has led to new opportunities, it also increased the challenges for the organizations that create and utilize such systems.

Conceptualization of a system's architecture, as expressed in an architecture description, assists the understanding of the system's essence and key properties pertaining to its behaviour, composition and evolution, which in turn affect concerns such as the feasibility, utility and maintainability of the system.

As per ISO/IEC/IEEE 42010:2011, an architecture (in the context of a system) is the fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution.

Architecture descriptions are used by the parties that create, utilize and manage modern systems to improve communication and co-operation, enabling them to work in an integrated, coherent fashion. Architecture frameworks and architecture description languages are being created as assets that codify the conventions and common practices of architecting and the description of architectures within different communities and domains of application.

Architecture descriptions have many uses by a variety of stakeholders throughout the system life cycle. Uses for architecture descriptions include, but are not limited to:

- as a basis for system design and development activities;

- as a basis to analyze and evaluate alternative implementations of an architecture;
- as development and maintenance documentation;
- documenting essential aspects of a system, such as:
    - intended use and environment;
    - principles, assumptions and constraints to guide future change;
    - points of flexibility or limitations of the system with respect to future changes;
    - architecture decisions, their rationales and implications;
- as input to automated tools for simulation, system generation and analysis;
- specifying a group of systems sharing common features (such as architectural styles, reference architectures and product line architectures);
- communicating among parties involved in the development, production, deployment, operation and maintenance of a system;
- as a basis for the preparation of acquisition documents (such as requests for proposal and statements of work);
- communicating among clients, acquirers, suppliers and developers as a part of contract negotiations;
- documenting the characteristics, features and design of a system for potential clients, acquirers, owners, operators and integrators;
- planning for transition from a legacy architecture to a new architecture;
- as a guide to operational and infrastructure support and configuration management;
- as support to system planning, scheduling and budgeting activities;
- establishing criteria for certifying implementations for compliance with an architecture;
- as compliance mechanism to external and project and/or organization-internal policies (for example, legislation, overarching architectural principles)
- as a basis for review, analysis, and evaluation of the system across its life cycle;
- as a basis to analyze and evaluate alternative architectures;
- sharing lessons learned and reusing architectural knowledge through viewpoints, patterns and styles;
- training and education of stakeholders and other parties on best practices in architecting and system evolution.

# 2 Scope of work

- Study existing literature on Systems architecting, standards on Reference Architectures for emerging technologies and systems
- Identify the key concepts involved in the architecture description of systems
- Develop a brief guideline for drafting standards on Architecture Frameworks for complex systems.

# 3 Methodology used in the work

- Studied the existing literature in the area of systems engineering and systems architecting using books and online resources
- Held number of discussions with domain experts in the area through virtual meetings
- The discussions and literature study provided a better understanding of the common concepts in the area of systems (software) architecting and in Standards on Reference frameworks. It also helped in identifying some of the inconsistencies and deviations in the standards published by ISO, and IEC.
- Based on the above findings, a recommended template for drafting standards on reference frameworks for complex systems was prepared.

# 4 References

## 4.1 ISO/IEC Standards

a) ISO/IEC/IEEE 42010:2011 'Systems and software engineering – Architecture description'
b) ISOIEC 30141 IoT RA ISO/IEC 30141 Internet of Things (IoT) – Reference architecture
c) ISO/IEC 17789 Information technology – Cloud computing – Reference architecture
d) ISO/IEC 20547-3 Big data reference architecture – Part 3: Reference architecture
e) IEC 63240-1:2020 Active assisted living reference architecture and architecture model – Part 1: Reference architecture
f) ISO/IEC TR 38504:2016 Governance of information technology – Guidance for principles based standards in the governance of information technology

## 4.2 Other Sources

a) System architecture - strategy and Product development for complex systems (Auth: Edward Crawley, Bruce Cameron, Daniel Selva)
b) ISO/IEC Directives, Part 2 Principles and rules for the structure and drafting

c) The TOGAF® Standard, Version 9.2
d) http://www.opengroup.org/
e) www.wikipedia.org

# 5 Summary Literature reviewed

As part of the action research, the following international standards on reference architectures were reviewed to understand the way each of the standards defines and describes reference architecture in the subject area:

- ✓ ISO/IEC/IEEE 42010:2011 'Systems and software engineering – Architecture description'
- ✓ ISO/IEC 30141 IoT RA ISO/IEC 30141 Internet of Things (IoT) – Reference architecture
- ✓ ISO/IEC 17789 Information technology – Cloud computing – Reference architecture
- ✓ ISO/IEC 20547-3 Big data reference architecture – Part 3: Reference architecture
- ✓ IEC 63240-1:2020 Active assisted living reference architecture and architecture model – Part 1: Reference architecture

## 5.1 ISO/IEC/IEEE 42010:2011 'Systems and software engineering – Architecture description'

ISO/IEC/IEEE 42010:2011 is one of the foundational standards for Architectural description.

This Standard addresses the creation, analysis and sustainment of architectures of systems through the use of architecture descriptions. It also provides a core ontology for the description of architectures. This International Standard also specifies provisions that enforce desired properties of architecture frameworks and architecture description languages (ADLs), in order to usefully support the development and use of architecture descriptions.

## 5.2 ISO/IEC 20547-3:2020 'Information technology – Big data reference architecture – Part 3: Reference architecture'

ISO/IEC 20547-3:2020 specifies the big data reference architecture (BDRA). The reference architecture includes concepts and architectural views.

The architecture in the standard defines the following two architectural viewpoints:

a) a user view defining roles/sub-roles, their relationships, and types of activities within a big data Ecosystem;
b) a functional view defining the architectural layers and the classes of functional components within those layers that implement the activities of the roles/sub-roles within the user view.

## 5.3 ISO/IEC 30141:2018 'Internet of Things (IoT) – Reference Architecture'

ISO/IEC 30141:2018 specifies a general IoT Reference Architecture in terms of defining system characteristics, a Conceptual Model, a Reference Model and architecture views for IoT.

The standard defines the following:

a) Characteristics of IoT systems
b) IoT Conceptual Model
c) IoT Reference Model
d) IoT Reference Architecture (RA) views
    i. functional view
    ii. deployment view
    iii. networking view
    iv. usage view

## 5.4 ISO/IEC 17789 Information technology – Cloud computing – Reference architecture

The Standard specifies the cloud computing reference architecture (CCRA). The reference architecture includes the cloud computing roles, cloud computing activities, and the cloud computing functional components and their relationships.

The standard defines 'user view' and 'Functional view'

## 5.5 IEC 63240-1:2020 Active assisted living reference architecture and architecture model – Part 1: Reference architecture

This standard specifies the AAL reference architecture and defines concepts and introduces terminology. It further provides generic rules for designers of AAL systems and services with the aim to facilitate systems design and enable interoperability between components.

This document identifies safety, security, privacy, and other requirements for AAL systems such as usability, accessibility, and trustworthiness (reliability, resilience).

This standard describes reference architecture in terms of defining AAL on a conceptual level. No viewpoints are defined in this standard. However, this standard provides security requirements in the context of AAL.

## 5.6 Comparison of the reference architecture description

A comparison of the structure and contents of the above standards were done. It has been observed that the documents are not consistent in terms of the architecture description.

Table 1 - Comparison of standards

| Table of contents of standards on Reference Architectures | | | |
|---|---|---|---|
| **ISO/IEC 17789:2014** | **ISO/IEC 20547-3:2020** | **ISO/IEC 30141:2018** | **IEC 63240-1:2020** |
| 1 Scope | 1 Scope | 1 Scope | 1 Scope |
| 2 Normative references | 2 Normative references | 2 Normative references | 2 Normative references |
| 3 Definitions | 3 Terms and definitions | 3 Terms and definitions | 3 Terms, definitions and abbreviated terms |
| 4 Abbreviations | 4 Abbreviated terms | 4 Abbreviated terms | 4 General |
| 5 Conventions | 5 Conventions | 5 conformance | 5 Relationship between IoT and AAL |
| 6 Cloud computing reference architecture goals and objectives | | 6 IoT RA goals and objectives | |
| 7 Reference architecture concepts | 6 Big data reference architecture concepts | 7 Characteristics of IoT systems | 6 AAL reference architecture |
| 8 User view | 7 User view | 8 IoT Conceptual Model (CM) | 7 Security requirements in the context of AAL |
| 9 Functional view | 8 Cross-cutting aspects | 9 IoT Reference Model (RM) | |
| 10 Relationship between the user view and the functional view | 9 Functional view | 10 IoT Reference Architecture (RA) views | |

| | | | |
|---|---|---|---|
| Annex A – Further details regarding the user view and functional view | Annex A (informative) Mapping big data RA functional view to other system integration RA | 10.2 IoT RA functional view | |
| | Annex B (informative) Examples of the relationship of roles in big data ecosystem | 10.3 IoT RA system deployment view | |
| | Annex C (informative) | 10.4 IoT RA networking view | |
| | | 10.5 IoT RA usage view | |
| | | 11 IoT trustworthiness | |
| | | Annex A Interpreting UML Class diagram for Conceptual Model | |
| | | Annex B Entity relationship tables for the CM | |
| | | Annex C Relation between CM, RMs and RAs | |
| Bibliography | Bibliography | Bibliography | Bibliography |

From the structure of the standards reviewed it was evident that these standards are not consistent and there are no common structures. Some of the findings of the review is listed below.

IEC 63240-1:2020 AAL Reference architecture is very brief and describes the architecture only at a conceptual level. No viewpoints are described in the standard.

Both Big data reference architecture (ISO/IEC 20547-3:2020) and Cloud computing reference architecture (ISO/IEC 17789:2014) describe the architecture with 'user view' and 'Functional view'.

ISO/IEC 30141 IoT reference architecture is more extensive. It describes the reference architecture through a number of steps, i.e. it describes the IoT conceptual model, IoT reference model, and then reference architecture with four views i.e. IoT RA functional view, IoT RA system deployment view, IoT RA networking view, IoT RA usage view. This standard also describes the characteristics of IoT Systems in detail.

# 6 Architecture Descriptions – an Overview

The standard ISO/IEC/IEEE 42010:2011 is one of the foundational standards for architecture descriptions used world over. The standard provides the core concepts in the process of architecture description. This section explains the core concepts in the process of architecture description as defined in ISO/IEC/IEEE 42010:2011.

The architecture of a system constitutes what is essential about that system considered in relation to its environment. There is no single characterization of what is essential or fundamental to a system; that characterization could pertain to any or all of:

- system constituents or elements;
- how system elements are arranged or interrelated;
- principles of the system's organization or design; and
- principles governing the evolution of the system over its life cycle.

Architecture descriptions are used to express architectures for systems of interest. Figure 1 depicts key concepts pertaining to systems and their architectures as a context for understanding the practice of architecture description.

> NOTE: The same system could be understood through several distinct architectures (for example, when considered in different environments). Architecture could be expressed through several distinct architecture descriptions (for example when different architecture frameworks are employed). The same architecture could characterise more than one system (for example a family of systems sharing a common architecture)

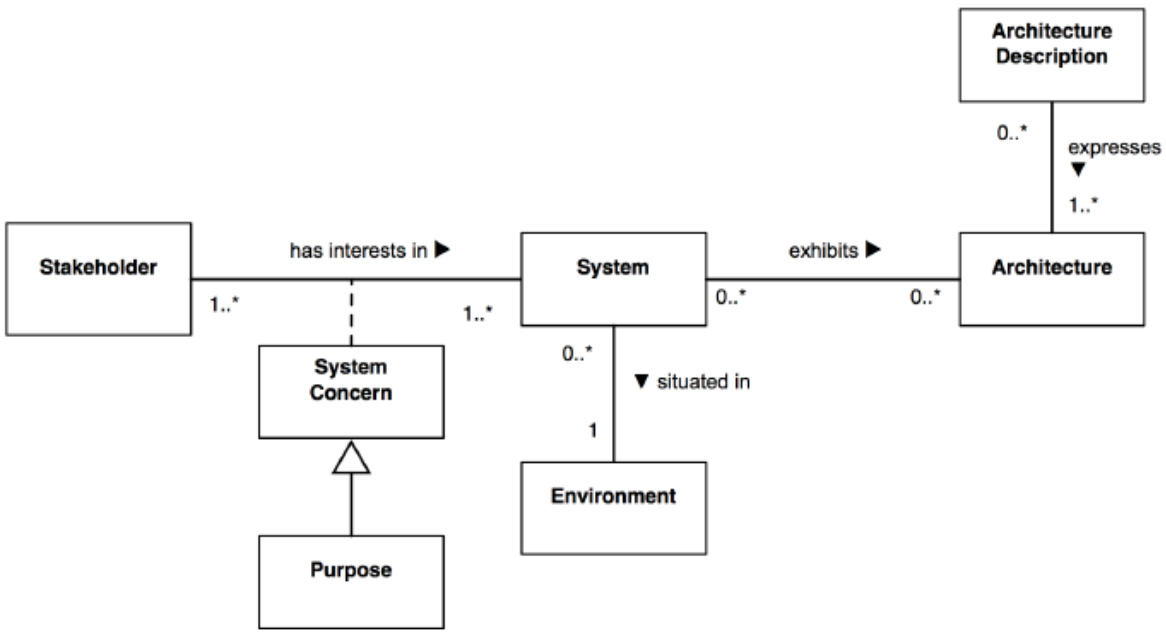


Figure 1 Context of architecture description

## 6.1 Conceptual model of an architecture description

An architecture description expresses an architecture of a system-of-interest.

### 6.1.1 Stakeholders and concerns

Stakeholders of a system have concerns with respect to the system-of-interest considered in relation to its environment. A concern could be held by one or more stakeholders. Concerns arise throughout the life cycle from system needs and requirements, from design choices and from implementation and operating considerations. A concern could be manifest in many forms, such as in relation to one or more stakeholder needs, goals, expectations, responsibilities, requirements, design constraints, assumptions, dependencies, quality attributes, architecture decisions, risks or other issues pertaining to the system.

### 6.1.2 Architecture views and viewpoints

An architecture description includes one or more architecture views. An architecture view (or simply, view) addresses one or more of the concerns held by the system's stakeholders. An architecture view expresses the architecture of the system-of-interest in accordance with an architecture viewpoint (or simply, viewpoint). There are two aspects to a viewpoint: the concerns it frames for stakeholders and the conventions it establishes on views.

An architecture viewpoint frames one or more concerns. A concern can be framed by more than one viewpoint. A view is governed by its viewpoint: the viewpoint establishes the conventions for constructing, interpreting and analyzing the view to address concerns framed by that viewpoint. Viewpoint conventions can include languages, notations, model kinds, design rules, and/or modelling methods, analysis techniques and other operations on views.

### 6.1.3 Architecture models

An architecture view is composed of one or more architecture models. An architecture model uses modelling conventions appropriate to the concerns to be addressed. These conventions are specified by the model kind governing that model. Within an architecture description, an architecture model can be a part of more than one architecture view.

### 6.1.4 Architecture Description (AD) elements and correspondences

An AD element is any construct in an architecture description and is the most primitive construct. Every stakeholder, concern, architecture viewpoint, architecture view, model kind, architecture model, architecture decision and rationale is considered an AD element.

A correspondence defines a relation between AD elements. Correspondences are used to express architecture relations of interest within an architecture description (or between architecture descriptions).

Correspondences can be governed by correspondence rules. Correspondence rules are used to enforce relations within an architecture description (or between architecture descriptions).

### 6.1.5 Architecture decisions and rationale

Architecture rationale records explanation, justification or reasoning about architecture decisions that have been made. The rationale for a decision can include the basis for a decision, alternatives and trade-offs considered, potential consequences of the decision and citations to sources of additional information.

Decisions pertain to system concerns; however, there is often no simple mapping between the two. A decision can affect the architecture in several ways. These can be reflected in the architecture description as follows:

a) requiring the existence of AD elements;
b) changing the properties of AD elements;
c) triggering trade-off analyses in which some AD elements, including other decisions and concerns, are revised;
d) raising new concerns.

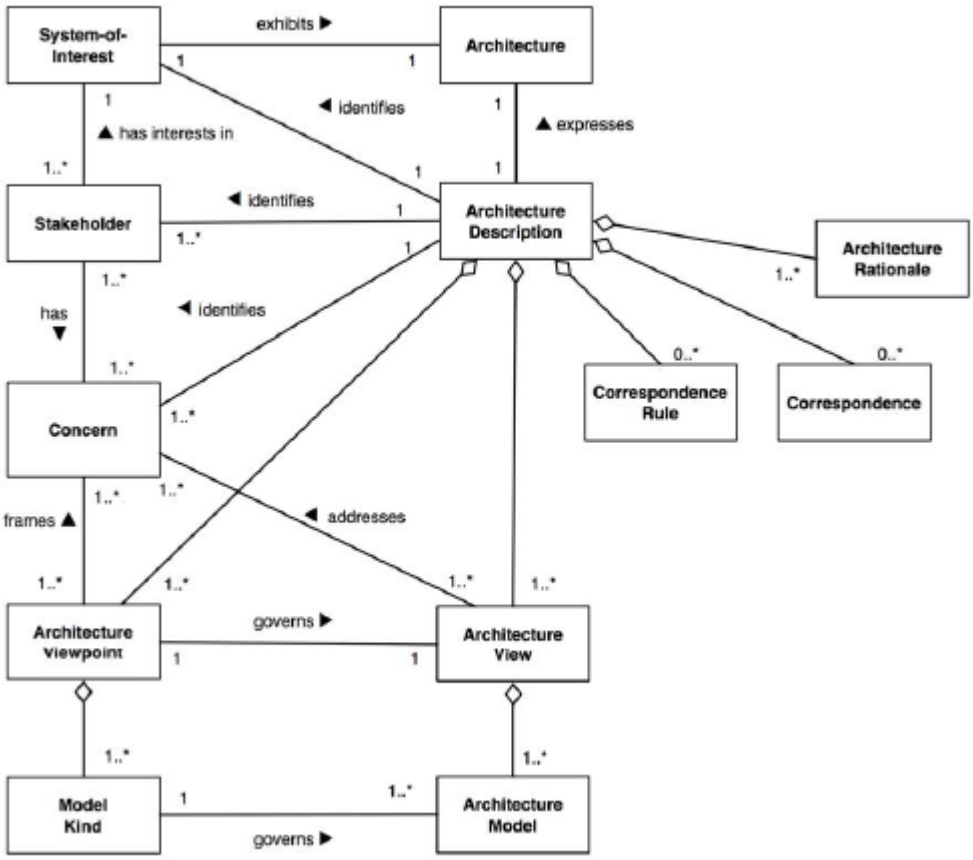


Figure 2 — Conceptual model of an architecture description

## 6.2 Architecture descriptions

As mentioned in ISO/IEC 42020, an architecture description should contain the following:

a) architecture description identification and overview information;
b) identification of the system stakeholders and their concerns;
c) a definition for each architecture viewpoint used in the architecture description;
d) an architecture view and architecture models for each architecture viewpoint used;
e) applicable AD correspondence rules, AD correspondences and a record of known inconsistencies among the architecture description's required contents;
f) rationales for architecture decisions made;

### 6.2.1 Architecture description identification and overview

An architecture description shall identify the system-of-interest and include supplementary information as determined by the project and/or organization.

The detailed content of identifying and supplementary information items shall be as specified by the organization and/or project.

### 6.2.2 Identification of the system stakeholders and their concerns

An architecture description shall identify the system stakeholders having concerns considered fundamental to the architecture of the system-of-interest.

The following stakeholders shall be considered and when applicable, identified in the architecture description:

a) users of the system;
b) operators of the system;
c) acquirers of the system;
d) owners of the system;
e) suppliers of the system;
f) developers of the system;
g) builders of the system;
h) maintainers of the system.

The following concerns shall be considered and when applicable, identified in the architecture description:

a) the purposes of the system;
b) the suitability of the architecture for achieving the system's purposes;
c) the feasibility of constructing and deploying the system;

d) the potential risks and impacts of the system to its stakeholders throughout its life cycle;
e) maintainability and evolvability of the system.

An architecture description shall associate each identified concern with the identified stakeholders having that concern. In general, the association of concerns with stakeholders is many-to-many.

### 6.2.3 Architecture viewpoints

An architecture description shall include each architecture viewpoint used therein and each included architecture viewpoint shall specify:

a) one or more concerns framed by this viewpoint (as per 6.2.2)
b) typical stakeholders for concerns framed by this viewpoint (as per 6.2.2)
c) one or more model kinds used in this viewpoint
d) for each model kind identified in c), the languages, notations, conventions, modelling techniques, analytical methods and/or other operations to be used on models of this kind
e) references to its sources.

Each concern identified in accordance with 6.2.1 shall be framed by at least one viewpoint.

### 6.2.4 Architecture views

An architecture description shall include exactly one architecture view for each architecture viewpoint used and each architecture view shall adhere to the conventions of its governing architecture viewpoint.

Each architecture view shall include:

a) identifying and supplementary information as specified by the organization and/or project;
b) identification of its governing viewpoint;
c) architecture models that address all of the concerns framed by its governing viewpoint and cover the
d) whole system from that viewpoint;
e) recording of any known issues within a view with respect to its governing viewpoint.

### 6.2.5 Architecture models

An architecture view shall be composed of one or more architecture models and each architecture model shall identify its governing model kind and adhere to the conventions of that model kind. An architecture model may be a part of more than one architecture view.

### 6.2.6 Architecture relations

An architecture description shall record any known inconsistencies across its architecture models and its views.

> NOTE: While consistent architecture descriptions are to be preferred, it is sometimes infeasible or impractical to resolve all inconsistencies for reasons of time, effort, or insufficient information. In such situations, known inconsistencies are to be recorded.

An architecture description should include an analysis of consistency of its architecture models and its views. Correspondences and correspondence rules may be used to express, record, enforce and analyze consistency between models, views and other AD elements within an architecture description.

#### 6.2.6.1 Correspondence and correspondence rules

Each correspondence in an architecture description shall be identified and identify its participating

AD elements. Each correspondence in an architecture description shall identify any correspondence rules governing it.

# 7 Common elements in the architecture framework

Based on the above analysis, it is recommended that the following common concepts are to be considered while defining architecture for systems.

- ✓ Information identifying the architecture framework
- ✓ The identification of one or more concerns
- ✓ The identification of one or more stakeholders having those concerns
- ✓ One or more architecture viewpoints that frame those concerns
- ✓ Any correspondence rules
- ✓ Stakeholder concerns
- ✓ Key principles
- ✓ System characteristics and properties
- ✓ Conceptual Model
- ✓ Reference Model
- ✓ Architecture views and Viewpoints
- ✓ Architecture relations
- ✓ Correspondence and correspondence rules

# 8 Proposed structure for standards describing architecture framework for complex systems

1. Introduction
2. Scope
3. References
4. Terminology, Symbols and Abbreviations
5. System overview (architecture description identification and overview information)
6. Stakeholders and concerns
7. Key principles
8. Systems characteristics/properties
9. Architecture views and viewpoints
    - 9.1. System conceptual model
    - 9.2. Reference Model
    - 9.3. Architecture Views
    - 9.4. Architecture relations, Correspondence, and Correspondence rules

8.1 to 8.12 provides a brief description about the aforementioned elements. As specified by IS 12, the elements 'Introduction', 'Scope', 'References', and 'Terminology, Symbols and Abbreviations' are mandatory elements. Other elements are optional and can be included in the architecture description as appropriate to the system of interest. The overall drafting and presentation of standard shall be as prescribed in IS 12.

## 8.1 Introduction

The Introduction provides specific information or commentary about the technical content of the document, and about the reasons prompting its preparation. The Introduction is an informative element and shall not contain requirements.

## 8.2 Scope

To be defined as specified in IS 12.

## 8.3 References

To be defined as specified in IS 12.

## 8.4 Terminology, Symbols and Abbreviations

To be defined as specified in IS 12.

## 8.5 System overview

System overview provides a brief description of the system in consideration. As there are multiple ways of describing an architecture of a system, it is important to provide a brief

of the architecture description followed in the particular standard. Therefore, this section should also describe the way the reference architecture is defined (or organized) in the standard including brief introduction of various components in the architecture description.

## 8.6 Stakeholders and concerns

As given in 6.2.2, an architecture description shall identify the system stakeholders having concerns that are fundamental to the architecture of the system-of-interest.

An architecture description shall associate each identified concern with the identified stakeholders having that concern. In general, the association of concerns with stakeholders is many-to-many.

## 8.7 Key principles

The architecture description should identify the key principles governing the system. The benefit of a principles-based standard is that such a standard can identify the value and outcomes of applying the principles without specifying explicit methodologies, structures, processes and techniques. This enables the development of guidance that can be applied on a consistent basis and gives organizations flexibility in how they implement the guidance within their own structures and processes.

## 8.8 Systems characteristics/properties

This section describes the key characteristics and properties of the system.

## 8.9 System conceptual model

Conceptual models are high level abstractions of things in the real world, whether physical or social. It depicts the key concepts involved in the system and the relationship among them. It provides the stakeholders a high level abstraction view of the system.

## 8.10 Reference Model

An abstract framework for understanding significant relationships among the entities of an environment, and for the development of consistent standards or specifications supporting that environment

## 8.11 Architecture views and view points

As described in 6.2.3 and 6.2.4, an architecture framework should provide architecture views and view points appropriate to the system of interest. An architecture view is a representation of a system from the perspective of a related set of concerns. An architecture can be expressed using multiple views that are appropriate to the system of interest. Each architecture view needs to represent the whole system from the perspective of the system concerns framed by its governing viewpoint. Example of architecture view are functional architecture, technology architecture, information

architecture, security views, data view, business information view, performance view etc. etc.

## 8.12 Correspondence and correspondence rules

As mentioned in 6.2.6, the architecture description should provide the architecture relations, correspondence and correspondence rules. A correspondence defines a relation between AD elements. Correspondences are used to express architecture relations of interest within an architecture description (or between architecture descriptions).

Correspondences can be governed by correspondence rules. Correspondence rules are used to enforce relations within an architecture description (or between architecture descriptions).