The user concept in the space industry and how this frames satellite missions, with a focus on social development in Africa

Kechil Kirkham

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Supervisor: Professor Peter Martinez

SpaceLab

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Abstract

Space-derived data lies untouched in data vaults, while many potential use cases for space applications are not exploited by the space industry. This gap may exist because the conceptualisation of the user in the satellite industry is too narrow, and yet influences the architecture and thence outcomes of a satellite mission. Assumptions about users and markets are not made on the basis of data and market research, in itself typically difficult to obtain, especially in Africa. This results in a lack of understanding of the end user and their social and economic context which feeds back to inadequately scoped requirements in satellite design. The reasons for this are not solely the limited imaginations and culture of practice of satellite engineers, but the structure of the space industry itself and its design frameworks. This limitation has impact especially for developing country applications, where the user and beneficiary concept elide in often unexamined and unchallenged ways. The satellite industry, part of the wider space industry, could borrow usefully from the IT industry in its relationship to the user and methods of deriving user requirements; in fact could consider itself part of the IT/data industry. This study explores the relationship between satellite design and the users of space-derived data, and how this is being affected by new disruptors to the traditional space industry. The implications for potential users in Africa are considered.

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Preface

The futurist Arthur C. Clarke, quoted in the UNESCO 1968 report 'Communications in the Space Age' said:
'Thanks to a few tons of electronic gear twenty three thousand miles above the equator, ours will be the last century of the Savage; and for all mankind, the Stone Age will be over.'(UNESCO 1968)

At that time, in the 1960s, with WWII decades behind and new technologies abounding, a clear line was drawn in the sand between primitive savages and a phrase common in my childhood: 'Modern Man.' This work aims to show that, although we have progressed technologically very much along the lines foreseen by Arthur C. Clarke, some aspects of our thinking remain parochial and determined by what is expedient. Our organisational and political structures reinforce a lack of fit between supply and demand.

The social and political benefits provided by satellite technology which he and the UNESCO report predicted for developing countries have been slow to come about, but they are happening in spite of the entrenched structures in the space industry. They are happening because other industries are stepping in to provide the applications users want and need.

'Everywhere we remain unfree and chained to technology, whether we passionately affirm or deny it. But we are delivered over to it in the worst possible way when we regard it as something neutral; for this conception of it, to which today we particularly like to do homage, makes us utterly blind to the essence[1] of technology.' (Martin Heidegger from his essay 'The Question Concerning Technology' first published in German in 1949).

[1] The original German word is *Wesen,* translated to 'its true meaning', but it can also mean 'coming to presence'. Both uses are prevalent in his texts, and he plays with this linguistic subtlety.

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List of Acronyms

AARSE	African Association of Remote Sensing and the Environment
ADD	Attribute Driven Design
ADM	Architecture Development Method
AfriGEOSS	African Group on Earth Observation
API	Application Programming Interface
ARM	African Resource Management
ATAM	Architecture Tradeoff Analysis Method
BBS	Broadcast Satellite Services
BPR	Business Process Reorganization
BT	British Telecom
CDR	Critical Design Review
CEO	Chief Engineering Officer
DANIDA	Danish Aid Agency
DMCii	Disaster Monitoring Constellation for International Imaging
DoDAF	Department of Defense Architecture Framework
ECSS	European Co-operation for Space Standardisation
EO	Earth Observation
FSS	Fixed Satellite Services
GEO	Group on Earth Observation
GIS	Geographical Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GUI	Graphical User Interface
HCI	Human-Computer Interface
HTS	High Throughput Satellite
IBM	International Business Machines
ICT	Information Communication Technologies
ICT4D	Information Communication Technologies for Development
IEEE	Institute of Electrical and Electronic Engineering
IS	Information Systems

ITAR	The International Traffic in Arms Regulations
JAD	Joint Application Design
LDCs	Least Developed Countries
LEO	Low Earth Orbit
MESA	Monitoring for Environment and Security
MMI	Man-Machine Interface
MSS	Mobile Satellite Services
NGO	Non-Govenmental Organization
PC	Personal Computer
PDR	Preliminary Design Review
RASCOM	Regional African Satellite Communication Organization
RDM	Requirements Definition Management
RE	Requirements Engineering
SAR	Synthetic Aperture Radar
SDLC	Systems Development Life Cycle
SDP	Science Data Processor
SEI	Software Engineering Institute
SKA	Square Kilometre Array
SMAC	Social, Mobile, Analytics, Cloud
SMAD	Space Mission Analysis and Design
TAFIM	Technical Architecture Framework for Information Management
TAM	Technology Acceptance Model
TOGAF	The Open Group Architecture Framework
TQM	Total Quality Management
TRA	Technology Readiness Assessment
TT&C	Telemetry Tracking and Control
UAVs	Unmanned Aerial Vehicles
UI	User Interface
USAID	United States aid agency
UTAUT	Unified Theory of Acceptance and Use of Technology
VSAT	Very Small Aperture Terminal
WIMPS	Windows Mouse and Pointer Systems

1 Introduction

Systems engineering provides the method used to design and develop space missions. Methods, processes and techniques in systems engineering are designed to ensure that the end result of the space mission conforms to what was expected in the initial conception. It rests on an assumption that there is a distinction between the mission designers (engineers) and those who have commissioned the mission and desire its end results (usually a client). Construction, launch and operations will likely be performed by different parties, and therefore documentation and commonly understood processes are critical to successful alignment and outcomes of the various mission phases.

The most influential phase of the systems engineering process is the definition of requirements, and entire fields of study have arisen addressing requirements, with their own conferences, journals and methods. This is all to ensure that there is agreement between the designers of the space mission, those responsible for its construction and eventual deployment, and those paying for it.

Important in early requirements definition is a concept called ‘the user’. When systems engineers are designing interfaces, at some point there will be an interface to something called a user, or perhaps a UI (user interface). Many assumptions are made, consciously and unconsciously, about the user, and since user requirements influence many other design considerations downstream, the user concept flavours the entire mission. The systems engineering process, oddly, does not demand a thorough understanding of this user, and this is what is examined by this research.

When the systems engineering method was conceived, in Bell Labs in the 1940s, the main customer driving the need for a more methodical approach to the design of complex systems was the US military. Military concerns continue to dominate space mission design. Now, space missions and their beneficiaries have moved out of the military realm, and today almost everyone in the world is reliant on, and touched by, space systems. This is not to say that a military approach to requirements definition is bad for design, only that it is worth examining whether the techniques developed by

and for the military work for applications very far removed from the highly mechanical machine-to-machine worlds of almost 80 years ago. Then, users were highly trained operators, not as today, where users form a much more diverse group of individuals.

This dissertation puts forward the argument that the conceptualisation of the user in the satellite industry is overly narrow, and this underpins architectural design and thence outputs of a satellite mission. The space industry could borrow usefully from the IT industry, software in particular, in its methods of deriving and treating user requirements, in fact could consider itself part of the IT/data industry. The space segment is only one part of a very long chain from data to end users, and this latter part of the chain is largely ignored by the space industry. The 'end user' concept itself is not always present in design thinking, that being the person who actually utilises space-derived data for a particular end.

This limitation has impact especially for developing country applications of space technology, where the user and beneficiary concept elide in often unexamined and unchallenged ways. Assumptions about markets and user behaviour are not made on the basis of market research, typically difficult to obtain in Africa. A lack of understanding of the end user markets feeds back to inadequately scoped requirements in satellite design, resulting in a fragmented and lengthy value chain.

It is the design engineers who make untested assumptions about the user and pay this concept inadequate attention, and engineers who work within developing countries (such as the author) typically remain in their thinking within a particular social and political idiom, and have scant exposure to potential beneficiaries and the eventual end user. Clients who procure space systems are also guilty of a similar narrow focus in terms of how they perceive the end users (and those clients are also engineers). Evidence for this lies in unused and under-utilised satellite data, plus the converse, which is potential end user applications currently unrealised.

Hard, direct evidence for these vaults of untouched satellite-derived data is difficult to obtain. Commercial agents and governments are understandably reluctant to divulge such statistics, though one can see through the operation of markets for space imagery

that the demand *for the specific material being made available* is not as widespread as anticipated. Geopolitics plays its part: when the US released LANDSAT data for free, this immediately destroyed the commercial market for similar imagery from rival providers.

This dissertation is structured as follows. Chapter 2 deals with the user concept, comparing its treatment in the IT and space industries. It describes a particular use case which scopes the problem and provides substantiating background and rationale for this study. The social context of the user is questioned, which is an area rarely discussed in engineering circles, but which has huge impact on the business model and delivery mechanism for space-derived data.

In Chapter 3, the design methods of the satellite industry and IT industry are compared. This entails an exposition of systems engineering frameworks and those adapted and adopted within IT. Although systems engineering frameworks were initially ported into the IT industry, these were soon rejected or substantially modified, and only superficially applied in practice. The IT industry has created new methods, and although these borrow heavily from the original systems engineering frameworks, they are looser, lighter, and more cyclical in nature. IT industry frameworks have had to consider the end user more thoroughly in order to survive (although Windows users may not think so), given the fast turnaround from concept to market, and *perceived* risk-tolerant environment.

The business models and value chains involved in space mission design are further unpacked in Chapter 4, where we consider so-called ‘disruptive’ technologies in space, and ask whether these are engendering an enlarged or better user concept in the space industry. So-called disruptive or ‘NewSpace’ borrows from the IT industry using lighter and faster methods of design, ignoring the usual risk-averse approaches in the space industry, and crushing the design-to-market cycle. If disruptive technologies are more responsive to market demand, does the user concept have a greater role to play? Some examples are examined from industry.

We finally investigate the developing country angle and ask what makes a space application suitable for developing countries and whether there is there in fact any distinction. This discussion explores what we may mean by a developing country need, and why this is important. Are there barriers to developing applications for developing countries? Is a financially poor user different to a wealthy user in a developed country, and what are the implications for the satellite industry and the emergent players in Africa?

Note that the terms "space industry" and "satellite industry" are sometimes used interchangeably. Since the goal of this research is to look at the way specifically end user needs are addressed in developing countries, the component of the space industry germane to this discussion is the satellite industry; namely those who commission and design satellites and take care of satellite-derived data. Increasingly, alternative high-altitude vehicles, which are not satellites, also form part of this landscape.

This study represents a novel view on the space industry, exploring some unchartered territory, gleaned after a lifetime's working practice in academic, commercial and government settings. References supporting this view have not been readily available to support all statements, which have been formed through recent personal communication with industry practitioners as well as prior work experience. Technical and business rhetoric have been deliberately minimised, since these tend to be tautological and it is too easy to judge technical writing by its weight of acronyms and current business idiom, rather than by what it is attempting to convey.

Methodologies used for this research are necessarily broad. The chief research method consists of desk research using both academic and commercial publications. Case studies and personal interviews are also used and explicitly described as such.

2 The user concept in the space and IT industries

2.1 A case study illustrating the lack of socio-political awareness of the end user in the space industry

In the boardroom of a South African space engineering company several engineers, including the author, met in 2016 to discuss a funding opportunity for Earth Observation projects in Africa. This was driven by a well-resourced national space agency which had drawn up a project specification for a targeted domain: agri-tech. The Request For Proposals included data about the agricultural sector in various African countries. The purpose of the meeting was to determine whether it was worth putting together a consortium to address the vertical application suggested by the funding programme.

In composition the meeting included highly educated senior technical personnel, and those who ran commercial engineering businesses; all satellite engineers. The discussion covered a possible business model and the complexities of involving different entities, from legal to engineering to government. Since the domain was agri-tech, a use case was discussed, and the prime user in this use case was 'the farmer'.

Assumptions were immediately made about this user which were not challenged in the meeting. It was taken for granted that this farmer was a relatively wealthy, resourced and capacitated individual. He (always, he) owns his land, and has a computer linked to the Internet, but he probably won't be able to perform image processing. The assembled agreed that he would need to receive information, not raw data. When pressed, they presented a fairly detailed description of this farmer, his habits, his car, his workers, his social and work context, his needs and aspirations.

Discussions focussed for a while on the nature of image processing, on the type of images he would need in order to make decisions regarding crop management, and other types of Earth Observation (EO) data. There was further discussion about the type of machines he may have and the image resolution he may require commensurate

with his plot size, type of crop etc. The putative imager on the satellite's payload was conjectured at some length, constellation characteristics for the area of Africa to be viewed, and general type of satellite required. Finally, the market size was considered; how many land-owning IT-savvy farmers are there in South Africa? Is this really worth it?

The data sheet handed out before the meeting and provided by the funding agency contained information about the farming sector and about the beneficiary (user) of the project. This is what it said about them:

> 'The project aims to reach out to support a minimum 150,000 smallholder farmer households in three-five years. Seventy per cent of the target beneficiaries will be women.'

Although the assembled had access to the document describing the target user, they preferred, and adopted, their own concept of the farmer when formulating the use case. In fact, when the actual beneficiary target was pointed out to them, the assembled immediately lost interest as the beneficiaries were perceived as too difficult to reach, insufficiently wealthy, and did not represent a worthwhile endeavour, even though the market size was far greater than originally thought. The meeting disbanded a few minutes later.

This case study presents first-hand a scenario where a user concept in a developing country context is unexamined, and a project thrown out on account of a poorly understood user concept. The image in Figure 2.1 is not what the engineers visualised when they imagined the concept of 'farmer'. There may well have been many other worthy reasons why this project was not undertaken, but the primary decision to reject it was based on a lack of understanding of the user.

This vignette provides the rationale for this research, and leads onto a more thorough examination of user concepts and how they shape satellite and mission design. This chapter explores the concept of the user in the space and IT industries, and the position the user occupies in the design process. It exposes the boundaries of the

space industry and asks whether these boundaries are helpful in creating proper alignment between user needs and industry solutions.

Figure 2.1: *A Ugandan farmer in Entebbe District (author's photograph taken in 2000).*

2.2 The scope of the space and satellite industries

Sending rockets into space, the Cold War, and putting a man on the Moon, are common public conceptions of what the space industry does, and historically fairly accurate. Military and science applications have been the mainstay of space activities since the 1950s, but with time, space technology and its functions have moved increasingly into the civilian realm. Telecommunications, entertainment, the Internet, mobile telephony and a plethora of global navigation satellite systems and Earth

Observation applications mean that space technology reaches almost every person on the planet. Without satellites modern life would not continue in its present form.

According to the well known space economist Pierre Lionnet, the space sector is defined as the industrial and institutional sector involved in the design, development and manufacturing of space systems. A space system is an infrastructure element with scientific, strategic or commercial objectives, with one or more critical components residing in outer space. This space system is composed of:

- A space launch system
- A spacecraft
- A ground infrastructure
  - Satellite TT&C, satellite uplink/downlink stations
  - Launch sites (and tracking stations)
- One or many consumer end-terminals (Lionnet, 2014)

The consumer end-terminals (e.g. satellite receiver, GPS etc.) are not always considered as part of the space system, nor is the ensuing data. The applications which use space-derived data are also not usually considered part of the space system, according to Lionnet. In this paradigm, space systems are understood to comprise solely the ground-based and space-based technological elements involved in the collection, generation, and/or transmission of data.

Governments continue to control space systems, and although commercial entities do design satellites and their ground segments, governments still perform an important regulatory function in space affairs and are still the predominant clients (i.e. funders) of the majority of space activities.

As Lionnet argues, space powers are defined by their capacity to develop, produce and operate space systems. They are not evaluated according to end-user services using data derived from space. These services belong to different sectors of society and business. Evaluating the industrial (commercial) component of the space industry is very difficult. Few countries publish recurrent annual statistics of space industry activity. Mostly this is restricted to launch events, and does not cover downstream

services. Entities which use space-derived data are fragmented and encompass many disparate government, research, and commercial sectors.

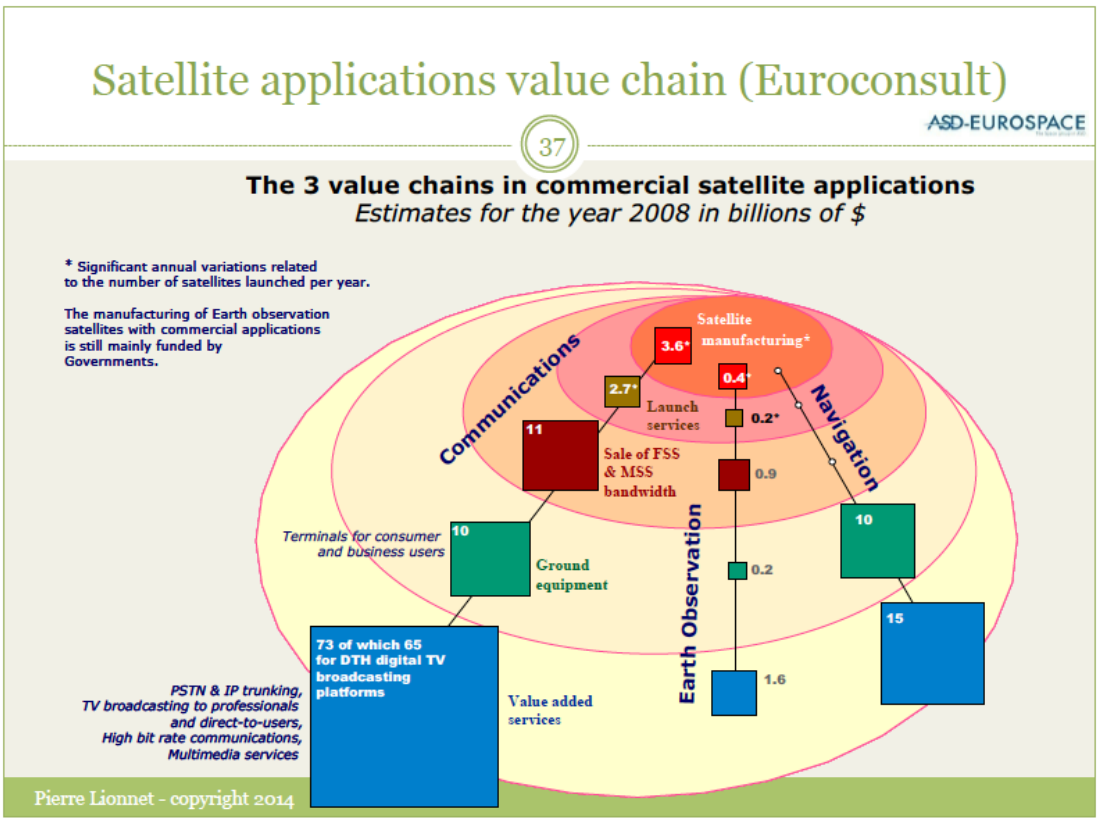

Figure 2.2: *Satellite applications value chain (not to be reproduced without permission of copyright holder, P. Lionnet).*

Applications using data derived from space are not considered, by 'space powers' to be part of the space industry, but are considered instead part of other technology-driven businesses, in particular the Information Technology (IT) sector. The IT sector, on the other hand, sees space as being just another location from which data can be extracted for their applications, and sees no obstacle in tackling the extraction of that data themselves, now that barriers to entry have fallen somewhat. This issue is further explored in Chapter 4 under the rubric of 'disruptive technology'.

Although the space industry sees itself as the developers of technologies to get objects into space, the space value chain shown in Figure 2.2 depicts the majority of the monetary value residing in the end user applications. The bias of space industry endeavour is not concentrated on the applications side of the space value chain. Applications are the functional units which end users engage with, and if the space

industry is not directly concerned with end users, then where in the value chain is this link made, and what are the consequences of this hiatus?

Figure 2.3 shows satellites by their function, and these relate to the applications of those functions. In 2016, the majority lay in the commercial telecommunications sector (37%), and 51% of satellites were taken up by some form of communications. Only 14% of satellites operate as civilian remote sensing platforms, and 7% used for navigation applications. In terms of end user applications, that is, functions carried out by people directly using space data, these are in the minority in terms of numbers of satellites.

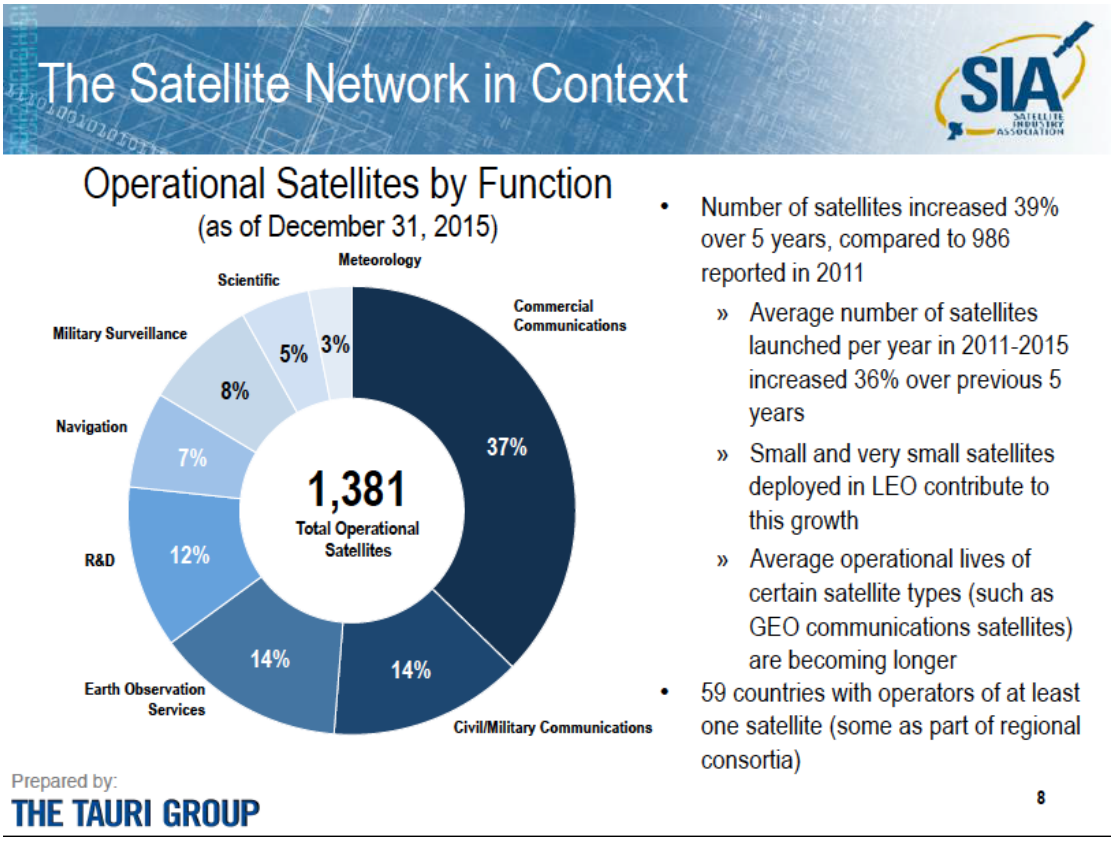

***Figure 2.3**: Operational satellites by function (State of the Satellite Industry Report 2016, Satellite Industry Association, 2016).*

If the problem statement is that space-derived data languishes untouched in data vaults, and there are those who could use space data but cannot access the right format/periodicity/resolution etc., then it follows that there must be a gap between

supply and demand for a particular reason. This reason could well be due to the distance between end users and technology developers in the space industry.

If we are not concerned with the part of the space industry value chain which builds, launches, and services satellites when considering impact on end users, then we are looking at the space applications and remote sensing sectors. This comprises many different types of application, many of which use space data quietly, i.e. the user does not need to be aware that the data that powers their application comes from space. Figure 2.4 shows a range of satellite services and applications.

***Figure 2.4**: Satellite services and applications (Scott Madry, lecture slide, 2014).*

The services and applications shown here entail a wide range of different satellite sizes, orbital, and payload characteristics. Some of these will require a constellation of satellites in Low Earth Orbit (LEO) whereas others will require one geostationary satellite.

All of these services and applications have one thing in common: data. The data from the satellite is received by ground stations, processed, and variously distributed to players in the value chain who are involved in the creation of Information and Communication Technologies (ICTs). Eventually, some of this data reaches end users, or is incorporated into programs beneficial to a user-oriented process. These data and processes are taken up by those outside of the space industry itself (as identified by Lionnet and others), usually within the wide remit of the computer or digital technologies industries.

2.3 The space mission user

For many space missions the user is obvious, in particular for military satellites, space probes and science missions, such as visits to nearby celestial objects, and this user is a highly educated, tech-savvy scientist. In such cases, where it is possible to define the user explicitly, the space community often devotes significant industry effort to developing user interfaces to maximise the scientific return of a given space mission. For example, NASA has a Human Computer Interfaces (HCI) group (part of the Ames Research Centre in Silicon Valley) who designed interfaces for the MARS Rover amongst other space mission tools. Here, the HCI is concerned with how scientists can manipulate highly technical tools.

By contrast with the above situation, user in the EO and smaller satellite space projects, be they the maritime engineer who interprets SAR data, the disaster planner who purchases or curates satellite images, a person ordering an Uber taxi, or the client who approves a satellite payload design, is rarely made explicit and examined in any detail. This is a startling statement to make when any satellite engineer will attest to the careful interpretation of user requirements, and their importance in the design process (see Chapter 3). However a user requirement is not synonymous with a user, and neither is a ‘market’; both terms applied to a collection of putative users, usually in the commercial realm.

Although this term ‘user’ is in common parlance, it has a more technical meaning when applied to the design and development of digital technology. In the early days of computing there was no sophistication in employing this term; a user was simply

somebody who sat in front of a computer terminal. The end user is defined now as specifically a human being who engages with a piece of IT. They may or may not, these days, have technical knowledge. A 'user' is also not necessarily a human agent. They could be another computer program, robot, or even a complex technical process involving many components. This study concentrates on the end user; the human being who has to interact with a piece of technology and for whom a technological artefact is created. Since these terms are not formalised, it is worth exploring other stakeholder terms used synonymously with the term 'user', and these are unpacked below.

There are two realms in which the satellite engineer can conceive of their project: the commercial realm, which includes the value chain and business proposition, and the technical or design realm, where requirements are created and used as the basis for design work. Some design artefacts and processes span both realms. In small companies, which typically design smaller satellites, the same engineer will be involved with both business and technical matters. In a larger organisation, or for a larger space mission, most engineers will only be concerned with technical parameters. For the purposes of this discussion we look at the user concept and how broadly the user is treated for Earth Observation and small satellite programmes.

The Client

Within the space value chain, the relationship between the satellite designers and the client is crucial. This is the entity which pays the bills. User requirements (see below) are often created by or with the client, and this segment of design documentation dictates all future works and the eventual design and deployment of the satellite and its behaviour. This includes ground segment configuration, type of payload, size of satellite, orbital characteristics, constellation style (if more than one satellite), pass rates, and all non-operational data considerations. The satellite designers typically work only with the client to determine system requirements and do not communicate with the client's stakeholders or have recourse to end users if they are at all in the picture.

The End User

The end user may never be considered in the design of a satellite. That is, the people who will use the data derived from the satellite may not be (an important) part of a stakeholder map. To the satellite designers, these are the concern of the client and its stakeholders. They may even be unknown to the design engineers. The client may themselves have a client for whom they are procuring a satellite, for example a space agency procuring on behalf of a government department, and it may not even be this stakeholder who is concerned with the end user, but others who work in a different department within government, academia, research institutes and related organisations.

In terms of applications using satellite data, the chain is even more lengthy and complex. The range is broad and encompasses almost every person on Earth: those who use weather forecasts, EO imagery, GPS-based tools such as Uber, the general Internet user, telephony, power generators, TV stations, navigators, and so on. These applications all have their business models and value chains, and the leaf node of those chains is the end user.

The Consumer

In terms of market analysis, the consumer is the individual who pays for a service. This is distinct from a beneficiary who benefits from a service such as a public good, but doesn't directly pay for it. The consumer in a satellite value chain may not be tantamount to an end user. There is some ambiguity of terminology here. For example, a consumer may pay for satellite television services but is not an end user of technologies developed to bring that programme to their TV.

The Beneficiary

The beneficiary is the entity which will benefit from receiving the data, or from a service provided or enhanced because it receives data which has at some point derived from space. The beneficiary may not receive the data themselves, or ever manipulate it, process it, or even be aware that it exists. Nevertheless their lives are touched by

data which has come from space, and perhaps the entire enterprise of a space mission was conceived in order to address their concerns[2].

An example is provided in disaster management, where the beneficiaries may be citizens of a city. Satellite images show a sudden increase in cars in hospital car parks. This is the first sign of an epidemic in the absence of other visible causes (massive traffic accident, terrorist attack, tsunami etc.). Authorities are alerted and appropriate action taken. The beneficiaries are all those who may, or have, come into contact with an epidemic in the vicinity, where further disaster can be mitigated.

The Market

This is loosely referred to as a segment of amorphous and undifferentiated people who behave in a predictable or formulaic way, with common interests. Usually this term is applied when there is a commercial client or application.

Society

This term is often employed when referring to 'civilians' or non-military persons in general. It is used very loosely and usually without qualification by technologists in the space industry. The complex and two-way relationship between society and technology is a large research area that has been studied for a few hundred years. Some aspects of this are covered in Chapters 5 and 6.

Given this plethora of different usages of the word 'user' and what this term could mean when applied to the design of a space mission, it is necessary to home in on what matters to the central argument; how does the conception of the user relate to the design process? Various methodologies are discussed below which have been and are being used by the IT industry with respect to understanding the user, but first it is worthwhile examining how the designer gets to that knowledge about the user. It is

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[2] Satellite engineers schooled in the systems engineering approach and used to speaking of requirements may be confused by this reference to "concerns". This is a term used in architecture design, and goes beyond specific requirements to encompass business and other wider interests.

interesting to compare the distance, or stages, between the end user and designer in the IT and space industries, and various scenarios are sketched out below.

2.4 The IT user

IT has now become so pervasive and embedded in every day objects and processes that organisations no longer have an IT strategy. They may have technology roadmaps for specific value chains, and an IT department, but the latter are becoming service and support vehicles to the larger organisation, its offerings and clients. Technology creators have disrupted the normal boundaries of established industries, and continue to do so, the most famous example being the computer giant Apple, who took over the mobile phone sector. There are few industries untouched by the digital revolution of the past two decades. This includes the space industry.

The role of IT Departments themselves has diminished as other groups take it upon themselves to develop and deliver technology-based services and products to markets without their intervention. Marketing departments in particular are bypassing IT and delivering products (applications) straight to their stakeholders, since they have become increasingly expert in the processing and distribution of data. As technology artefacts become increasingly consumer-driven, the marketing departments find themselves in the best position to specify and deliver what their customers want, while IT departments adhere to a technology push model of product development. Data itself has become highly commoditised, and expertise in its manipulation and monetisation is now seen as distinct from IT. In previous decades, data processing was firmly part of computing, but has now become decoupled and a separate industry in its own right.

The effect of non-IT specialists developing data based products is disruptive to the established state of affairs. So-called disruption to the normal delivery chain can cause technical debt, a subject growing in topicality, as those who are not schooled in IT are increasingly engaging in technology creation and delivery. Technical debt is the accumulative effect of disregarding (especially non-functional) quality attributes in product development, resulting in eventual dysfunction of the developed system. A similar effect is being experienced in the space industry, where computer companies

and data providers are becoming involved in designing and developing satellites and managing the ground segment. Disruptive technology and technical debt are covered in Chapter 4, but it is not possible to give an overview of the IT industry without immediately pointing out its disruptive and pervasive nature, both of which have had an effect on the space sector.

For the purposes of this research, the IT industry is that segment of developers and providers who create solutions for users involving specifically digital technologies, whatever market sector they inhabit. Companies creating Information Communication Technologies (ICTs) began in the computing sector, designing and developing technologies connected to computers, and it is the history of this sector that is interesting to trace in the parallels it affords with the space industry.

There are three distinct segments connected to IT germane to the argument of this thesis. The traditional IT or computing sector creates digital machines and programs to run on them. Secondly there is the increasingly prominent data sector: those who create, process, add value and resell data. Thirdly there is the Information System (IS) sector which combines digital technologies, organisations, individuals, data, and processes. Often the term IS is applied to administrative systems and not distinguished from computing in any way. Each of these facets of the IT industry shares a common history in its dealings with the end user, and methods for dealing with its user base.

2.5 User Analysis

In the computing world there are many methods for eliciting user responses to technology and methods for characterising the user. These arise from a plethora of disciplines and actors involved in ensuring that what is produced is not only fit-for-purpose, but is appealing and appropriate in every way for particular markets.

It is worth sketching some of the history of end user involvement in early computing, around the 1980s. Early adopters of the Microsoft operating system and application software may recall the frustrations of doing battle with early incarnations of Windows. Apple Inc. (who arose from Xerox PARC) raised the bar in user-interface

design, realising that the more user-friendly and ambient the technology, the greater the returns. 'Human Factors', as anything non-technological involving human end users was termed, became fashionable, and some techniques for incorporating social factors were incorporated into actual system design processes.

In the early days, human factors research concentrated on ergonomics and cognitive psychology, focusing on the individual human and their characteristics rather than, as later, the entire procedural and environmental context of a specific interaction. Several methods arose to analyse the human component, and a brief description of some of these is given below. Many of these methods remain popular to this day.

2.5.1 Participatory design frameworks: JAD, 'collective resources' approaches, Technology Acceptance Model and others

The 'socio-technical systems' (Britain) and 'collective resources' approach (Scandinavia) came up with a broad set of techniques which could be termed 'Participatory Design' containing diverse methods for sharing the process of design between users and technologists. This came from a less corporate and more socialist set of values than those prevalent in the US at the time. The project of Participatory Design was to alter work practices. System design was seen as part of an approach to change work organisation and workplace structures.

Xerox PARC in the early 1980s was highly influenced by the European researchers, the author and associates included amongst their ranks. Those who developed their novel user-centric Operating System and UI technologies went on to form Apple Inc, while the European research spawned Acorn Computers, who went on to become ARM Plc and other successful computer companies.

Participatory Design empowers the individual worker to examine their own working practices, not only the products they produce. Total Quality Management (TQM) and Business Process Re-engineering (BPR) could both be said to be participatory design initiatives, where workers collude in their own re-organisation, and the customer (could be end user) becomes the focus of business unit activities. Both TQM and BPR transformed working practices and their outcomes (products) by placing the customer

and their goals first, over the authority of the technocrat. In traditional systems engineering by contrast, it is elegant technical solutions for which engineers are praised.

One of the problematic aspects of end users is their lack of knowledge of their own practices, business processes and working contexts; much of this knowledge is implicit. Researchers encountered problems eliciting implicit knowledge and tacit skills, which must be represented in the delivered system. For the European socialist-humanist perspectives, there was a greater recognition of the existence of politics in the workplace, conflicts of interest, and the unstructured nature inherent in the world of work, compared to their north American counterparts.

The user interface was the locus and focus of interaction between the computer system and the outside world, and became paramount in terms of the perceived success of the entire Information System (IS). A prime method to address UI design for both the European and American companies has been to send engineers into the workplace to observe closely the context of the user, and to have unstructured as well as structured discourses with them. These practices informed much of the early design of user-interfaces and the information systems they served.

IBM in America developed a practical methodology for involving users in design in 1977 called Joint Application Design (JAD), which continues to be popular. A set of formalised workshops (JAD sessions) with a cohort of typical users and designers facilitated by a JAD specialist brings together various perspectives and addresses the integration of users' needs as well as insight into corporate culture. This approach follows in the tradition of rationalist and functionalist design methodologies, where the problem (irrational users) can be contained by having them incorporated into a highly formalised and rational design programme.

However the agenda of the JAD process was very much controlled and dominated by the engineers. The users' influence on design is conveniently reduced to a well-structured functional input to the design process, a process which always remains in the control of the expert designers (Asaro 2000). While JAD at least acknowledges

the importance of users in the entire process, it does not overturn the status quo with respect to the power relations between the technocrats and users, nor acknowledges the political context and 'fundamental technical rationality' of the process. Furthermore, the JAD process is only applied during the early requirements gathering phase and thus users are a means to an end of finalising a requirements specification.

Understanding the user in the IT world is about more than creating a system which an individual can interact with on a technical basis. The system must fit within a workplace including business processes and a social framework. In addition, there are many subtleties involved in getting people to buy technology as well as buy into it, particularly if it is novel. Once a customer base is established there are further challenges in extending and prolonging customer loyalty. One of these subtleties is the distinction between actual use of a piece of technology and perceived ease of use. The Technology Acceptance Model (TAM) was created to draw out this distinction.

TAM is a widely accepted tool to represent users' decisions to adopt an information system, and their (perceived) satisfaction in using it. It combines ease of use and conformance to required functionality to predict continued use. It was originally developed to predict users' initial adoption of an IS but has been extended as a tool to examine users' relationships to a particular system. Its power lies in divorcing ease of use from perceived usefulness, which in itself is a more sophisticated view on the engineering-based view of satisfied requirements. Whereas at one time system testing would be carried out in laboratory conditions, testing against a series of quantitative measures determined beforehand, user testing is now carried out *in situ* and incorporates user perceptions and most importantly, qualitative responses. Lin and Silva (2005) remark that 'What an individual perceives as 'ease of use' and 'usefulness' may depend not only on intrinsic qualities of the information system but also on the changing contexts in which the information system is evaluated.'

In IT, satisfied requirements, as is usual in engineered technology, are not paramount and by no means are the only measure of success. These measure internal conformance to technological parameters only. More important than these are user perceptions. These can be shaped by ephemera such as advertising, the price point of the product, and a wide variety of attributes such as legacy systems, interoperability,

maintainability, future proofing, and whether the CEO likes it. The TAM, as shown in Figure 2.5, diverges significantly from the engineering body of knowledge, and provides an example of how the IS world treats the user in their complex social environment.

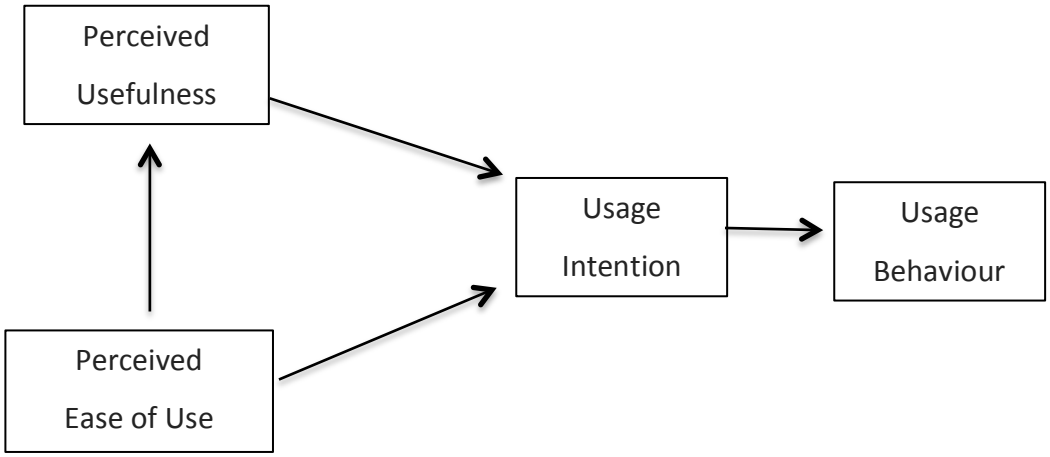

Figure 2.5: *Simplified Technology Acceptance Model (*(Hong et al. 2006).

This model has been refined by (Venkatesh et al. 2003) as the unified theory of acceptance and use of technology (UTAUT). This is a technology acceptance model which aims to explain user intentions to use an information system and subsequent usage behaviour. The theory holds that there are four key constructs: 1) performance expectancy, 2) effort expectancy, 3) social influence, and 4) facilitating conditions. This has greater applicability in cases where cultural norms and business practices cannot be assumed, such as those where a system is implemented in a different context to that in which it was conceived or with which researchers are familiar. The UTAUT model and its variants have been used extensively in ICT4D (see below).

2.5.2 The User Interface as a social and engineering problem

The traditional block diagram of an Information System shows a technical 'core' which performs the information processing. Data enters the system at one end, processing occurs, and information is output from the other end to, usually, an amorphous and undifferentiated user.

The IT-Based Information Processing block and the Human Information Processing block collude to produce the valuable Information in a 'constructivist model' where the user actively constructs sense out of the Information output. A degree of predictability is assumed at every stage. 'Chaotic' in the caption of Figure 2.6 means that behaviour is individualistic and thus 'generic assertions may not be helpful in any given situation' (Johnstone & Tate 2004).

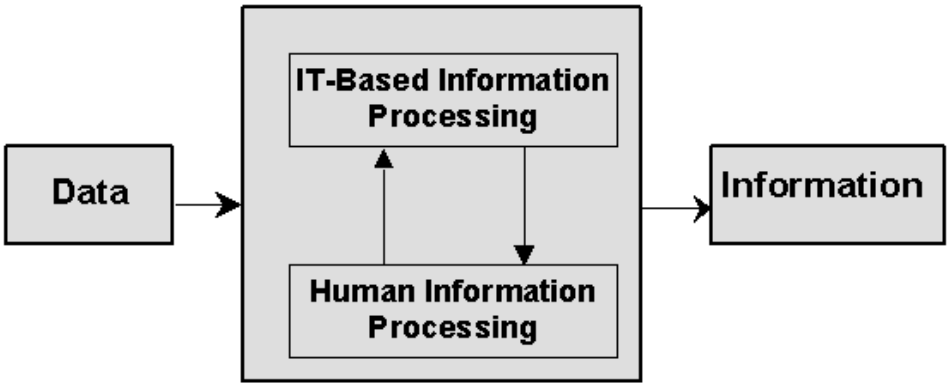

Figure 2.6: *An IS model incorporating both systematic (IT-based) and chaotic (human) information processing* (*Johnstone & Tate 2004*)**.**

In a traditional Information Systems view, 'the usefulness of these outputs in creating meaning and information for the person receiving them are not of concern to the IS development team, once the requirements for the input or output have been agreed' (Johnstone & Tate 2004), consistent with the view of the IS guru, Thomas H Davenport, who in 1994 spotted that 'technocrats are constantly caught off guard by the 'irrational' behavior of 'end users.' ' (Davenport 1994).

Johnstone and Tate's model describes human information processing as chaotic rather than systematic, meaning that the user behaves in a non-linear and unpredictable way. This is anathema to most engineers who seek to retire risk by ensuring as great a predictability in behaviour as possible.

A field of study arose in the 1980s initially called the Man-Machine Interface (MMI), now Human-Computer Interaction (HCI). HCI is about 'methods and tools for the development of human-computer interfaces' and 'draws on knowledge and skills

from psychology, anthropology and sociology' (Preece & Rombach 1994). Software Engineering is concerned with how software is constructed; the core algorithms and hardware requirements are determinate. They contain within them the prestige, satisfaction and glory of solving a problem. The human side of the HCI on the other hand is indeterminate, and human users unpredictable. Even today the UI, which is at the centre of HCI, can be relegated and be an afterthought in information systems design.

A case in point is the Square Kilometre Array radio astronomy project (SKA), whose Science Data Processor (SDP) is being designed by the author at the time of writing. The framework used for the design of the SKA is derived from space engineering, and ECSS[3] standards are referred to for the core approach. It is requirements-driven, and most engineers would be familiar with the outputs of the design work: a Requirements Specification, Functional Decomposition, Product Breakdown Structure, etc. The (indirectly) user-facing 'Delivery System' is not seen as a core part of the project. The beating heart of the SDP comprises the algorithms that perform the information processing, and those which regulate compute power and resources. The user is rarely mentioned, and indeed the Delivery System has spent some of its design life as an adjunct to the SDP, and it has often been questioned whether it needs to be part of the budget cost cap.

This is perhaps justified, since the SKA's intended users are well known (research astronomers), and are certainly not the public at large. It is assumed that the users are technically proficient and will understand the products emerging from the SDP. In a project of this grandeur and size, it continues to mystify how minor a part the Delivery System plays in the overall design. In this century, it is normal in IS design that the user and their needs are placed centre stage. Since the SDP is not described as an IS, but as a processing system, the user and their needs are relegated to a secondary role. This is allowable and normal in a project which adopts development standards from the space industry.

[3] European Co-operation for Space Standardisation, the provider of standards for most space and satellite engineering activities on Earth (and off it).

2.6 Social context of the Information System

As pointed out by Asaro (2000), Joint Application Design serves to protect and promote the authority of technical experts, and is the chief aim of attempts to involve the user. His critique of these methods involved a strong political angle, and what he observed was a group of expert technologists interrogating potential users in unfamiliar settings, often divorced from the technology they were supposed to be evaluating.

An important wave of UI design in ICTs comes from a key tool of anthropology: participant observation. This began to be employed as a technique to arrive at user experience in the late 1980s. Using this method, the researcher 'poses' as a 'native' and lives as closely as possible with their subjects. In this case, the engineer spends significant time shadowing users, noting what they do and how they interact with systems and processes in their organisations. Myers is one of the proponents of Design Ethnography, which goes beyond mere observation into active engagement with subjects during the period of research.

Traditionally in ethnographic research, the ethnographer attempts not to interfere with their subjects. However in the post-modernist and post-structuralist epochs, this has been found philosophically bereft, in that it is impossible for the ethnographer to be objective and not to influence their subjects, in a kind of 'Schrodinger's Cat' dilemma. Social Anthropology has sought to overcome this dilemma by admitting and exploring the anthropologist's personal affect and effect. This has come to be known as 'critical ethnography' and been scantily applied to Information Systems research. Baskerville and Myers report that in the most part, 'ethnographic research as currently described in the IS research literature does not include any active intervention on the part of the researcher' (Baskerville & Myers 2015).

They describe Design Ethnography as a relatively novel situation where the researcher acts as 'expert', performing two tasks at the same time: both observing and designing. This requires a considerable set of tools: immersion, interviews, social mapping, conversation analysis, archival research as well as 'co-planning and co-designing' workshops.

While their fairly recent paper sets out a new and more complicated approach to eliciting actual system design from a set of users, it is illustrative of the lengths the IT industry can go to in ensuring that an information system will satisfy its users. The skills required to enter into this particular realm of socio-technological research are rare and rarefied, and unlikely to be found outside of academia.

Note that there is no mention of UI design in this discussion of user requirements. These, along with other types of requirement may be more familiar to engineers in the space industry, but they are a design tool that is far too blunt to apply to the design of an information system. How this traditional engineering approach works with modern design frameworks is examined in the following chapter.

2.6.1 Distance between technology designer and technology user

The brief history of user involvement in IT design shows that over time, the distance between the technologist and the user has decreased. The technologist now wishes to know intimately how their system will be used *in situ*, and what users feel about it both before they have acquired the technology and while they are using it. The IT industry invests greatly in this enterprise. What is meant by this decreasing distance is that the steps required to move from designer to user have diminished.

In the early days of IT, the computing professional existed 'in a kind of organizational priesthood' (Holmes & Post 2002), and espoused a sort of disdain for users, where the uninitiated were to be avoided or pitied by the programmers. Operating systems required specialist skill and patience, training courses were necessary to learn any functional application, and experts could command high salaries. The closest computer professionals got to end users was through questions originating from the user base, posed to them by their long-suffering computer support teams, most of which were scoffed at.

This state of affairs soon changed for several reasons. Users organised into communities and became powerful in their relationship to the IT industry. The industry itself grew and competition for users meant pleasing them became important

for sales. Computing power increased, allowing for better performance particularly of any graphical user interface. The games industry drove graphical capability, which influenced operating system performance and usability. Unix-based WIMPS (Windows Icons Menus and Pointer Systems) were copied by all manufacturers and became the norm before computing shrank to the size of a mobile phone and we now have apps to carry out many computing functions. It wasn't only hardware improvements which changed ICTs but a change of heart in the computer industry, as it was seen that technology devices and computers with better user interfaces rapidly gained market traction. Consumer applications came to be designed for usability and it became important for the designers to know their clientele intimately.

The distance between technology designer and end user has had to decrease, to enable the developer or designer to understand the user better. In the IT world, it is usual for there to be several methodologies in place to allow the developer to access and understand their users. This is what one would expect in a consumer industry. While the space industry does not see itself as in the business of creating consumer products, the data created by space technologies most certainly is taken up by consumers. In various parts of the space industry, the end user or consumer is far removed from the engineer/designer or developer. Figures 2.7, 2.8, and 2.9 below show the typical distance between these actors.

Firstly, in the software industry, as would be expected, there is one step to the end user from the software developer. The developer can interrogate the user directly through the mechanisms of Beta trials, JAD sessions, TAM, and many other methods as discussed, including having user representatives in their Agile teams. 'To be most effective, computing professionals should work as closely as possible with the workers they support'(Holmes & Post 2002). Additionally, researchers and other experts are at their disposal, and the organisations employing the developer are equally concerned to create artefacts that the user will find palatable.

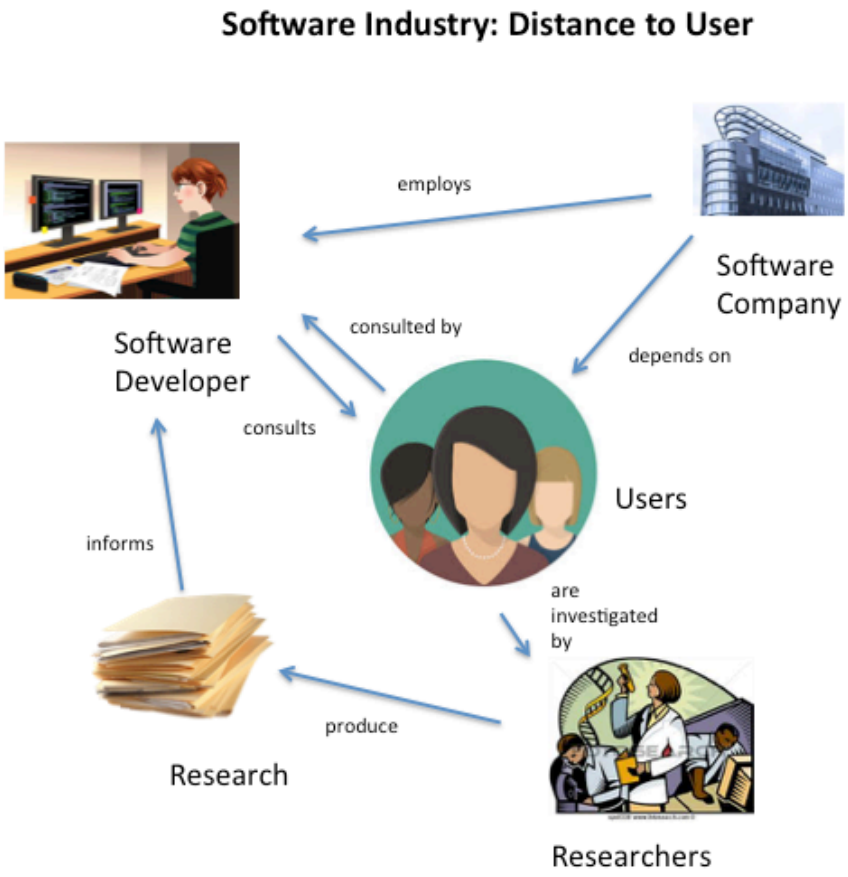

Figure 2.7: *Distance from designer to user in the contemporary software industry.*

The space industry, like the computing industry, is multi-faceted. On the whole there is an extremely large gulf between the designing engineer and the end user of the artefacts emerging from the far end of the value chain. There are many reasons for this: as pointed out at the outset the space industry sees itself as the purveyor of satellites, probes, space ships and a controlling ground segment. The 'user segment' is not central to their activities.

There are some parts of the satellite industry that are more concerned with the end user: those who provide entertainments in the form of satellite TV, or extra-terrestrial telephony and Internet services: these are named Fixed Satellite Services (FSS), Broadcast Satellite Services (BSS), and Mobile Satellite Services (MSS). A new generation of High Throughput Satellites (HTS) that can re-use frequency bands will replace many of these. However for these sectors, the user is mediated by other service providers. Those who deliver programming or telephony services to the user

represent a complex value chain in themselves, even though there has been recent consolidation of actors in this market. The satellite developers themselves do not usually provide end user applications in telephony and broadcasting. There is a growing number of subdivisions of communications satellite markets (Pelton, 2017), but just to examine the value chain in Broadcast Satellite Services it is obvious that there are many links from end user (viewer/audience) to satellite specifier. There is a complex relationship from those who determine programming for the consumer, and those who procure satellites. The consumer watches a programme; the broadcast service constitutes a host of players who collaborate to produce a suite of programming; the technology users are those who create the devices and dishes to receive the broadcast signal. A complex web of regulations, government entities, and commercial organisations occupy this chain, as shown in Figure 2.8.

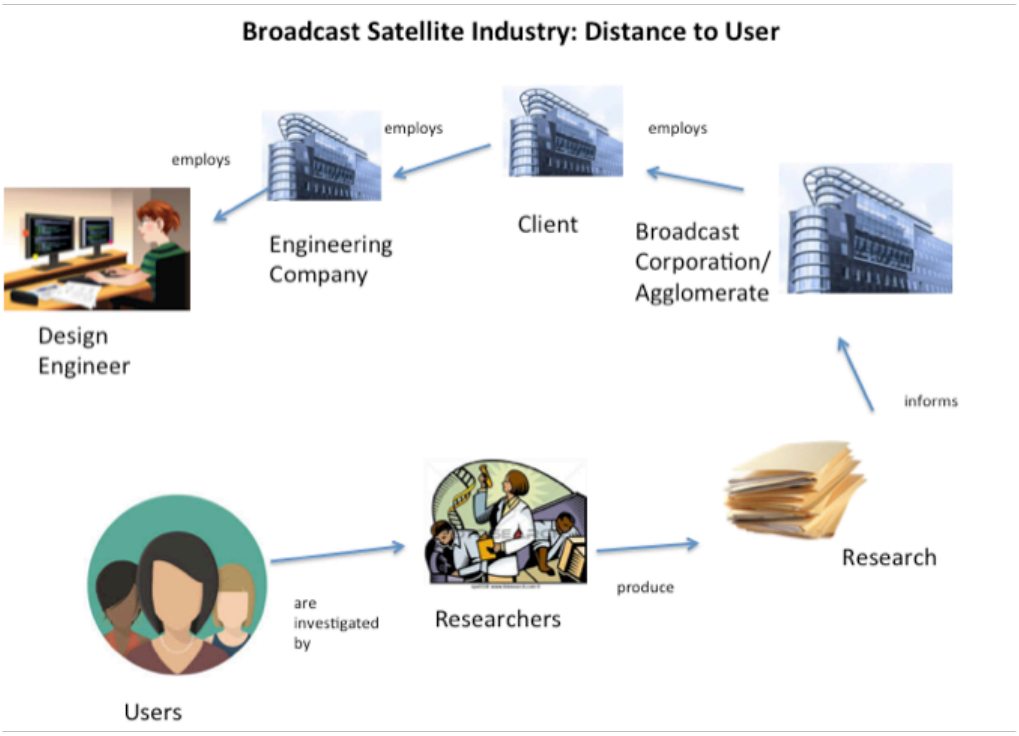

Figure 2.8: *Simplified model of distance from designer to user in the Broadcast Satellite Services industry.*

The satellite industry generally designs payloads and satellite componentry for their clients. Their design engineers are fairly remote from the end user, as shown in a simplified model in Figure 2.9 and their work is mediated through several agents. The Government-Client-Engineering-Engineering Company chain can involve many

intermediary organisations. There can be 'at least 20 organisations between the satellite designer and the end user' reports one satellite engineer currently working on small satellite design projects.

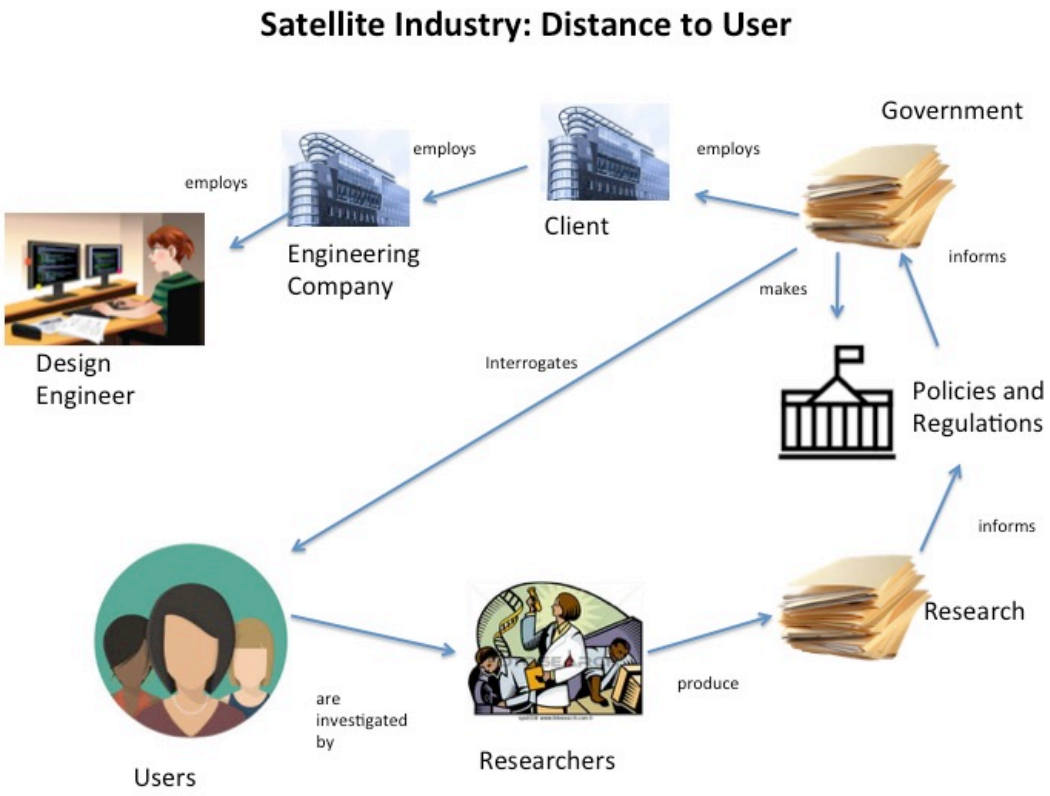

Figure 2.9: *Simplified model of distance between designer and user in the traditional satellite industry.*

The question as to why this distance should matter to those connected to the space industry is answered by examining parallels to the computing sector. Through time, as shown above, the computing industry has become increasingly concerned and connected to its users for commercial reasons. The fact that those who design satellites are disconnected from their user base suggests that what they design may not address users' concerns, and this may explain the gap central to this thesis between the space data provided by existing space systems, and the needs of markets for space applications. At each link in the chain (or node), a message becomes eroded. The clients, often governments whose term is of a particular duration, are not concerned about closing the loop between technology and need, once their Key Performance

Indicators have been satisfied. For some sectors of the space industry, this may not matter since their outputs and products are never evaluated by end users or consumers. This was the thinking in the early days of computing, and it was those who could reach out to end users who gained market prominence. The role of disruptive technologies plays a large part in the story of who has succeeded, and Chapter 4 will explore how far this is true in the space industry.

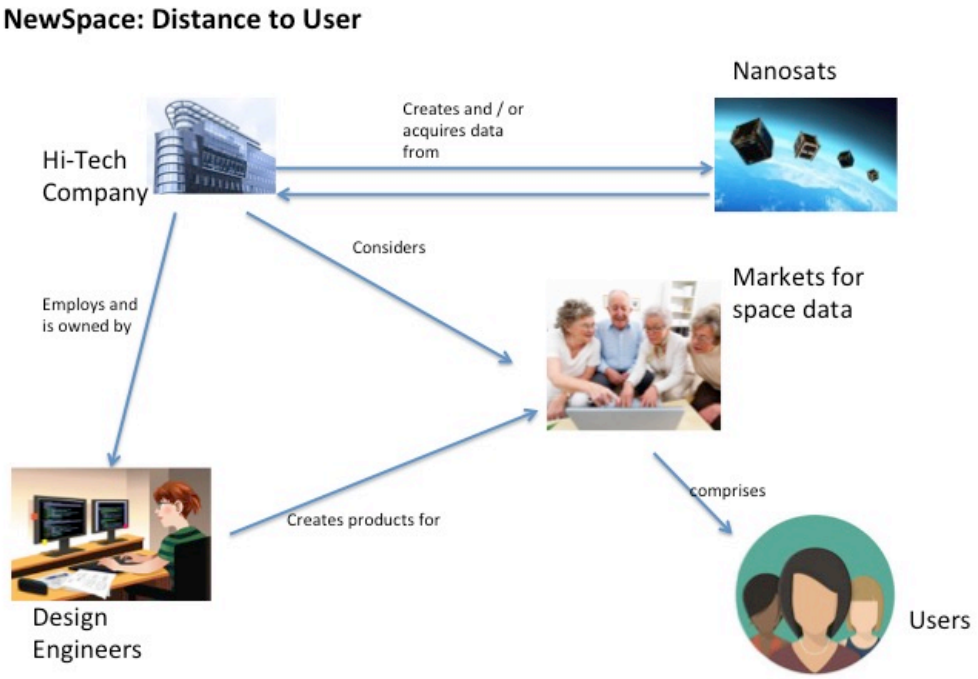

Figure 2.10: *Distance to user from NewSpace companies.*

'NewSpace' is a term given to a relatively recent wave of companies who are disrupting the status quo in the space industry. The case of the NewSpace disruptive companies is an interesting one. Figure 2.10 depicts the important facets of the relationship between them and users. Markets for space data are not necessarily well-defined by all NewSpace companies, but it is these rather than the end users themselves that drive their business models. There is a subtle distinction between markets and users. Whereas the IT industry was concerned (initially at least) with individual user experiences, both in terms of the ergonomic experience, ease of use and fit-for-purpose, NewSpace industries are aiming for markets for space data, and moreover intend to develop new markets. It appears that there are two types of

NewSpace business: those producing products for broad usage such as Planet, and those aiming for vertical[4] data markets such as Spire.

A lack of awareness of the business, social and political context of the user gives rise to risks of producing artefacts that the user does not want and cannot use. Behind the NewSpace model shown in Figure 2.10 there is no precise formulation of the end user, and this indicates a risk. High-tech companies can be quite comfortable operating in this environment if they can convince investors that there will be an eventual market for their products. The Design Engineer in this model creates systems and artefacts whose eventual use case(s) may not be mapped out. It is anticipated that only some NewSpace companies will prevail, and just as with the dotcom boom this will not be predictable. As with the traditional satellite system, in this model it is left to the IT sector to create the applications that people will use.

Although an end user application may be developed by the IT industry which ultimately gleans its data from space, the fact that the data itself is agnostic of that usage means that it cannot have been tailored for that application. For some, that doesn't matter, since the data is highly generalizable. GPS data for example is used by many end user applications, and when GNSS systems were designed and launched, they had no cognisance of the likes of UberEATS. However this study questions whether the space industry is wise to regard the end user as 'someone else's problem'.

What follows is a case study in the design and implementation of an IS which did not take local politics and local practice into account. Although this does not use specifically space-derived data, it serves to illustrate the problem, and is a rare example of an IT project designed for and implemented in a developing country. The gap between the end users and the designers was culturally and geographically very large, resulting in this case in a failure to achieve the aims of the project.

[4] Vertical markets address a specific function e.g. agritech

2.7 Case study showing the perils of a lack of socio-political awareness in IS design: computerising the Ugandan judiciary

In the late 1990s the Danish aid agency DANIDA decided to support the Ugandan judiciary by computerising caseload. The desired end result was to shorten waiting periods for accused awaiting trial, the majority of whom were innocent and could die while in prison. AIDS and malaria, overcrowding and neglect combined to erase the problem of lengthy trial periods in the worst way possible.

A further human rights abuse in the court system was that court officials were routinely bribed by wealthy relatives of some accused, while other inmates with poorer connections languished for longer and had a greater chance of dying while in custody. The court backlog was several years.

The author was in charge of the development of the judicial information system, which was composed of a fairly simple database-driven architecture and standard GUI for populating and retrieving information from the database. The system was duly installed, but it was plain to see that, although it had the potential to lend efficiency to the administration of caseload, it could not address the central iniquity of the system.

Firstly, the judges were limited in number and could only handle a set number of cases at any given time. Secondly, while under the paper system court officials were bribed to ‘lose’ or ‘find’ case files and change their rank on the court listing, now with the electronic system they could be bribed in exactly the same way. Although case files could not be technically lost (networks and backups were a routine component of the system) nevertheless criteria for selecting a hearing remained corrupt, and not based on any rational formula, such as length of time spent awaiting trial, type of offence, etc. Sadly it made no difference whether or not there was a paper or electronic system in place determining court appearance to the human rights issue. Millions were mis-spent.

Essentially DANIDA and various other stakeholders had not thought through the social and political aspects of the user or their work environment. They had

transposed a particular set of values and socioeconomic conditions to an entirely different country and situation. The DANIDA project manager, a highly trained legal expert, bemoaned the poor salaries of the court administrators who were not paid a living wage. In Uganda very few were, and even middle-class wages could not cover the demands from friends and relatives on the person with that rare commodity of a decent job. It was beyond the remit of the aid agency to interfere with Human Resources matters in the Ugandan judiciary, and it would have probably made no difference if they could, given the prevailing general poor economic conditions in the country and high incidence of bribery and corruption.

If an anthropologist, or one more sensitive to local socioeconomic conditions had been sent to design a system to lessen waiting time for court cases, they would most probably have designed it according to an entirely different approach, perhaps not involving IT at all. However in this case, once the technical ball had started rolling it was very hard to stop, as benefits such as 'modernisation' are thought of as coterminous with 'computerisation', and the project, crucially, had high prestige and a high price tag. The feedback loop from evaluator to aid agency, if honest, would not have resulted in a different UI or system. Aid agencies have a high churn rate particularly of field professionals.

This story illustrates several points central to this thesis: social factors are often ignored in system design; prestige continues to dominate high-level funding decisions, and beneficial outcomes are rarely attributed to a deft application of social factors research (or the converse). The IT industry may fare better than the space industry in its attitude to and treatment of the user, but the relationship is not perfect.

Although this story is concerned with a terrestrial information system in a developing country, similar stories play out when connected to applications which derive their data from space, and these are covered in Chapter 5. What follows examines how the initial scoping of a problem determines design decisions, and how architectural frameworks in different technological spheres including in the space industry compare with each other.

2

3 Architecture frameworks in the space and IT industries

Chapter 2 discussed the user and user concept in the Space and IT industries, probing the relationship between the development of space technology and end users, which takes place within an overarching architectural framework. In this chapter we turn our attention to the architecture frameworks themselves, and trace how the user concept is carried through from concept to design and eventual deployment. We turn the magnifying glass on that initial phase and examine the relationship between user requirements and the space value chain.

3.1 Space industry ontologies and boundaries

The space industry uses particular ontologies for describing its activities. These have arisen historically, based on sending objects into space during the Cold War. A 'mission' is different to a 'project' in one important way: it involves a 'missive', an object sent forth, and this missive is intimately connected to the goals of the project. This conception of a space project carries throughout, from initial idea to eventual 'deployment'. The user is not centre-stage; the missive (satellite/probe and payload) is key.

The mission, like its core missive, has a linear trajectory. Both technical and financial stages of the mission have their own known characteristics. Specialist engineers are engaged for particular stages and there are other expected resources attached to each phase. These phases are understood by all connected to the project, and each phase entails a particular list of deliverables, milestones and achievements.

The IT industry does not concern itself with a missive. End goals may be diffuse and not clearly linked to a technical development per se but instead, business goals. The user concept is strong in the IT industry, and in the early days 1950s – 1960s, there was one user concept, and this was the *operator*. This operator was educated, highly technical and proficient in the use of programming languages that demanded thorough knowledge of the hardware of a particular machine. By contrast, in the space industry

the user is coterminous with the client. The end user, the person who will actually use the data, is the province of the application generators who are not part of the space industry: these exist in telecommunications, entertainment, university research units, and increasingly at large in the general public, as described in Chapter 2.

Satellite engineers see themselves in an analogy with the IT industry as the space equivalent of "chip designers", who provide the platforms for collecting data from space. They are developing multi-purpose machines which only need to compete with other satellites. The end user is far down the value chain and taken care of by those who have use for the data returning from satellites. They see themselves as part of the space industry and a value chain whose end users are serviced by components beyond themselves and the space industry. They may analyse user requirements, and validate those requirements, but this is not a wide-angle exercise in new application creation. They do not see themselves as data providers, who happen to derive their data from space. A company which does just this is Spire, and their success story is described in the following chapter.

The hypothesis in this study is that, by relegating the user concept and focusing only on client requirements to drive satellite design, or at least payload design, the space industry is missing large potential new markets for space-derived data, and inadequately specifying payloads.

3.2 The value chain in the IT industry and the space industry

The value chain in both the space and IT industries is complex and there is no one blueprint. There is a great deal of overlap in technologies, design and development approaches between these industries, so much so that satellites have been described as 'computers in the sky', and increasingly, as we show in Chapter 4, the IT industry is encroaching into traditional space territory. In fact in the *State of the Satellite Industry Association Report 2005*, they are described as 'super-computers in the sky' in recognition of the increasing processing power of many modern satellites.

Grimard's view of the space value chain places 'Value Added Services' and 'Consumers' as the end-point of the chain, and hopes that profits from end user services can feed into expensive space infrastructure, whilst acknowledging the complex and fragile mechanisms which link these various actors (Grimard 2012). In his view, shown in Figure 3.1, there is a timeline from the satellite manufacturer through launch services, lease of satellite capacity, through to value-added services and thence to consumers. This is the typical mission pattern mentioned earlier, where the value chain is described as a project, or mission, which has a beginning, middle and end. The mechanism by which the end product can tie back into the start (space infrastructure) is not explicit in his research.

In reality there are many links between 'Value Added Services' and the 'Consumer' in Grimard's chain. If the consumer is a mobile phone user requesting an Uber, or downloading weather stats onto a mobile app, the chain from data acquisition to the end user is almost intractable. In fact, in the examples of Uber and many other mobile phone apps, they would not classify themselves as space applications, although, in the case of Uber, it relies on satellites not only for the basic telephony services but also vehicle tracking and navigation.

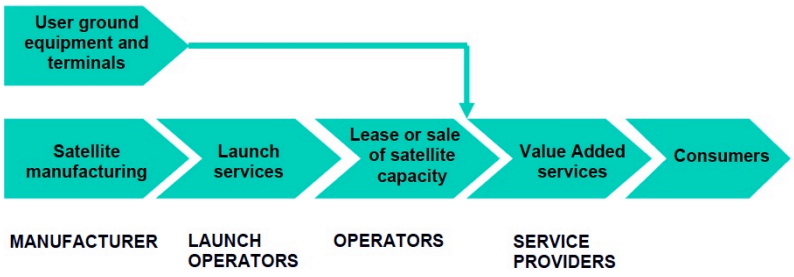

Figure 3.1: *The space value chain (Grimard, 2012).*

Situating a business model within a space value chain is not a predictable low-risk occupation. The European Space Agency created the Sentinel constellation believing that there would be general consumer markets for EO data, but, as they failed to materialise, have had to offer this imagery as a public good. The United States' GPS is another case in point, where a space technology was made available to the world at

large and has had massive consequences in terms of public benefit through an explosion of useful (and unforeseen) applications.

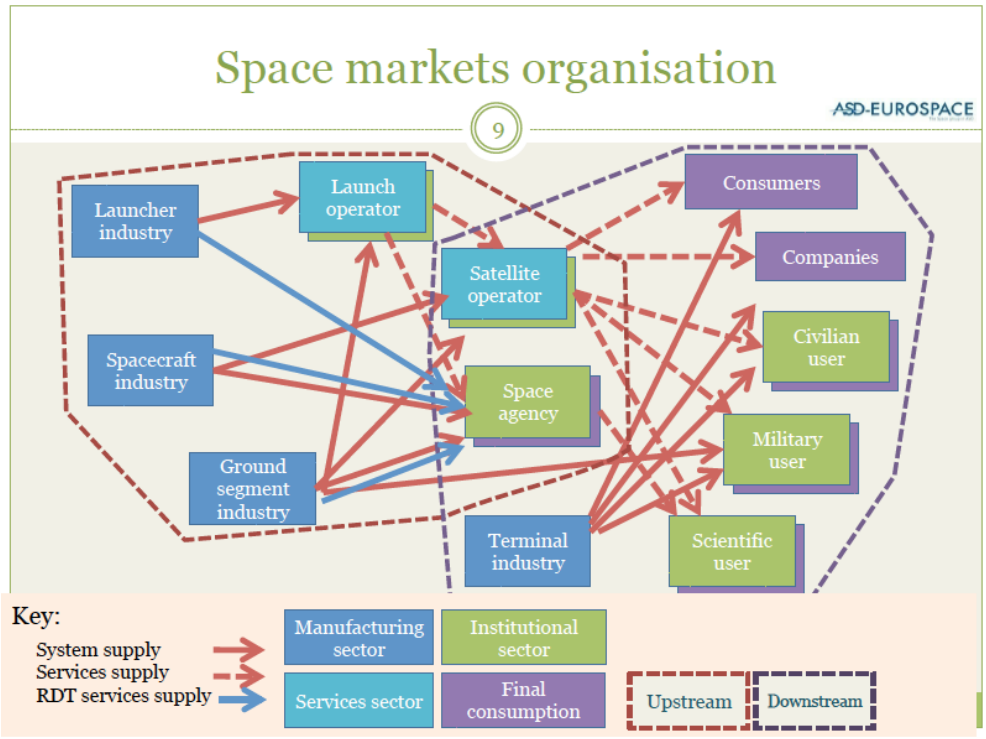

Figure 3.2: *Space markets organisation (reproduced by kind permission of P. Lionnet).*

Rather than describe the many specific value chains in the IT and space industries it may be more enlightening for the purposes of this argument, to see how space markets are organised. Figure 3.2 shows a view of space markets from the space industry perspective. Note the distinction made here between the 'civilian/Military/Scientific user' and 'Consumers' and 'Companies'. Given the military history of space endeavours and government procurement bias, this view does not characterise markets in terms of consumers with any sophistication.

3.3 Situating the user in space mission design

Schlagert wrote in 1953, about the new field of Systems Engineering that:

> 'The first stage, planning, is really an investigation of user needs, commercial or military. This stage is of value not only to the engineering department but also to the success of the organization as a whole. This area constitutes the

> weakest phase at present, since it demands the broadest background. Few engineers are trained in the fields of economics, psychology and marketing.'

There are now highly developed methodologies for all phases of systems engineering. Unlike in 1953, current university engineering programmes teach systems engineering routinely. Satellite missions are firmly embedded in systems engineering lore, and it is the method chosen to address how to progress from a broad mission concept to actual deployment of a satellite system. That system, from end-to-end, comprises recognisable industry standard phases using common reference models, such as has been published by the European Co-operation for Space Standardisation (ECSS) in many large volumes.

The ECSS documentation includes an element called 'Human Factors' which 'defines requirements for the integration of the human in the loop for space system products' (Secretariat ECSS Executive, 2008). However this refers to the human being in-flight or at a ground station; this human is not an end user. Applications, especially in the current mobile sense which use space-derived data are not germane to the ECSS standards, and the creation of such applications often falls outside the scope of a space mission.

In the usual systems engineering approach, each phase builds on the outputs of the prior phase, and thus the primary phase is the most influential. Underpinning the systems engineering method is the notion that design problems must be corrected as close as possible to the outset, as they become increasingly difficult and costly to solve with time. The first phase is requirements analysis and there are entire fields of enquiry, conferences and journals devoted to Requirements Engineering (RE) and Requirements Definition Management (RDM).

Because the entire end-to-end process of space mission design and deployment is very complex and technically demanding, its methods and techniques form a complete, established body of knowledge which the student engineer covers at university level. However, the engineer is not trained to use any formal analytical framework to establish who the end users are, or how to identify them. The 'human factors' material

in the ECSS standard texts does not cover such end users. Simply put, the training of satellite engineers and mission designers reinforces the status quo, i.e. that the space mission begins with technical requirements and ends at the ground station, and is a highly technological undertaking involving, primarily, machines.

Interestingly, formal frameworks for engineering which originated from space and heavy engineering have been adopted variously by computer industries. Computer programmers are often called 'software engineers', and most professionals in the IT industry will be familiar with architecture frameworks, whose origins may have come from space engineering. The IT industry, especially software development, has an ambivalent relationship to these methods, and by and large have adapted them for their own use. This is especially so in the part of the computer industry with the most user-intensity: Information Systems.

3.4 Life-cycle methodologies

The profession of Information Systems didn't emerge until the 1950's when computers were first applied to data processing and management problems. This early 'pre-methodological' phase could be characterised by 'seat-of-the-pants' approaches to systems design. Systems design was driven by the management of physical data, storage and retrieval concerns. Eventually roles became differentiated, and more formal methods were borrowed from the engineering worlds.

When, in the 1960s, standardized methodologies emerged, the IT industry adopted the 'life-cycle' view. This describes a series of stages beginning with requirements definition, through defining the components necessary for the system, through to algorithm creation, then managing the programming and testing of the system. Consulting users was not performed systematically, and users were frequently only brought in, if at all, during the final stages of the testing phase. If anything, future users were consulted through informal interviews during the initial requirements gathering phase, or perhaps during an evaluation of the commissioned system post-implementation.

In computer programming and systems design, the most prominent method is called the ‘Waterfall Model’, often referred to as the Systems Development Life Cycle (SDLC). The example below (Figure 3.3) is taken from a State University of New York course, but there are many variants, most involving Deployment or Maintenance phases. This diagram shows the Waterfall Model at its most simplistic, with feedback loops between some of the phases.

The Waterfall Model has been much refined and criticised but continues to underpin much systems design, even for those involved in the more modern Agile developments (see below). Its main advantage is that it highlights the importance of getting early design right. More recent techniques in software system development eschew the notion of any determinant rightness, but concede that it is more important to be happy than right, and the aim of a successful operational system is happy end users. Technical correctness, fit for purpose, and internal alignment between phases are not in themselves sufficient to produce user-delight. To an engineer or developer, elegant solutions and algorithms are most important, but not to the user and many other stakeholders.

The main criticism of the Waterfall Model is its tardiness and massive latency problems, and this has ramifications for the space industry and disruptive technologies. By the time each stage has been completed, verified, and an authority has cleared progression to the next stage, years may have elapsed. By the time systems testing is performed and, most essentially, the users are confronted with a Beta Release, competitors are at large, and clients frustrated. Efforts to accurately predict particularly software development durations, are notoriously over-optimistic. Inevitably, given the lack of early prototyping and exposure to or involvement of end users, the Beta Release is woefully lacking, and it’s back to square one.

The very name of the model betrays the fundamental problem with this method. A waterfall is a one-way journey, an ineluctable cascade; in reality IT development is cyclical. In the author’s experience in the IT industry an entire new computer had to be brought to market every 6 months, including chip set, operating system, Application Program Interfaces, programming languages, user applications, plus all

associated marketing. A one-way Waterfall Model with its concomitant documentation and authorisation-heavy procedures cannot produce a novel computer in 6 months.

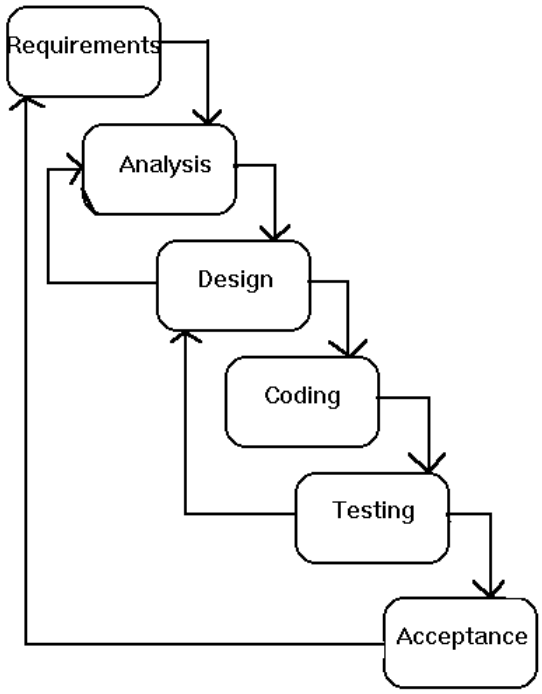

Figure 3.3: *The Systems Development Lifecycle (SDLC) or Waterfall Model.*

The Waterfall Model encourages poor communication between individuals and teams as functions are specialised and require authorised procedures and documents, and there is over-reliance on milestones rather than day-to-day problem-solving. A great length of time elapses before any examples of prototypes can be seen by stakeholders, and over-hierarchical management structures slow down each component of the process.

In response to this, the IT industry became somewhat anarchic, relying on highly talented individuals to carry through design and implementation in the absence of procedures and documentation. The companies that survived this epoch in the early 1980s were those whose people lived, played, and worked together and therefore had exceptionally good communications, precluding the need for heavyweight procedures. This became recognised in the IT industry and so-called Agile methodologies were developed in response.

Agile, as the name suggests, is a flexible and swift approach to software development which entails very early and rapid prototyping of small components, and small teams with daily communication rituals. Flat hierarchies are encouraged, which further aids communication. Teams are multi-functional, cutting across traditional functional silos, and the end user is often a member of a team in some way. Documentation is only created for specific purposes and often only on demand. Architecture-related documents do not need to be comprehensive.

Certain aspects of Agile methods would not be tolerable to a space mission design environment, where the chief aim is to retire risk. This entails considerable time and effort applied to thorough documentation, and 'sign-off' junctures where experienced authorities approve designs before continuing, introducing delays. Moreover, the entire process is predicated on the first stage, requirements, and these are contentious.

In response to the inadequacies of both the Waterfall Model and Agile frameworks, new approaches have been created to marry the best of both; for example the Scaled Agile Framework. Some version of this has been practiced by many organisations who find Agile only useful for development and not for product release. In software houses product release typically occurs according to marketing timelines and not development milestones, and this is a major departure from space missions. Separating development from products would not work with a traditional systems engineering framework for space, with attendant milestones that rest on development design reviews (PDR, CDR etc.).

3.4.1 Concurrent Engineering

In recognition of the pitfalls of the Waterfall Model, some parts of the space industry have adopted the practice of Concurrent Engineering. This is a design optimisation approach whereby teams develop separate functions or products simultaneously, by-passing the need to wait for one task to finish before another can start. The method relies on good communications between teams, using computer modelling and design techniques where certain parameters and models must be shared. The European Space Agency has built a Concurrent Design Facility and this is used for space mission development. Concurrent Engineering has been practiced for about 20 years, but is

not established practice in the space industry. It also doesn't address the fundamental problem of addressing the end user's needs and incorporating them into requirements and thence design.

3.5 Requirements: a critique

Space mission design rests on the correct formulation and validation of requirements. An increasing proportion of technical work involves software, but the application of Requirements Engineering to software development is flawed. Ralph, in 'The illusion of requirements in software development' polemically states that 'many software development projects may have no useful requirements' (Ralph 2013). Not all programmers are schooled in engineering, and there are often severe time constraints and chronic under-estimation of time required to produce a finished software product.

The European Space Agency's Software Engineering and Standardisation web page admits: 'Requirements engineering is currently identified as one of the weak points of the software development lifecycle.'

An increasing amount of effort in satellite projects is being dedicated to software development and maintenance. The Software Engineering Institute on the subject of Requirements Engineering:

> 'Requirements engineering is complex because of the three roles involved in producing even a single requirement: the requestor (referred to as the 'user' in the IEEE definition), the developer (who will design and implement the system), and the author (who will document the requirements). Typically, the requestor understands the problem to be solved by the system but not how to develop a system. The developer understands the tools and techniques required to construct and maintain a system but not the problem to be solved by that system. The author needs to create a statement that communicates unambiguously to the developer what the requestor desires. Hence, requirements address a fundamental communications problem.'

It is assumed that the user (requestor) understands their problem. However in high-technology situations, the user often does not, particularly the end user, and herein lies a further problem to add to the communications issues identified above.

When engineers talk of sound requirements, the emphasis is on their composition as statements. A requirement must satisfy a host of criteria, is a precise, technical formulation, and most importantly can be verified. We can agree that soundly composed requirements are important; they are a necessary step in development, but not sufficient to bring about the result of a useful, appropriate product.

At its most general, a requirement is a 'documented demand to be complied with' ECSS (ECSS-S-ST-00-01C1 Glossary of Terms. 2012). In practice requirements quickly become complex (see Figure 3.4). IEEE Standard 830-1998 states that ''a requirement specifies an externally visible function or attribute of a system [while] a design describes a particular subcomponent of a system and/or its interfaces with other subcomponents''

Requirements themselves should contain certain attributes. A valid requirement must meet many criteria, including:

- **Factual Correctness** – is factually correct
- **Completeness** – sufficiently complete
- **Consistency** – the absence of conflict within, and between, requirements
- **Clarity** – the syntax is easily understandable by the intended reader
- **Non-ambiguity** – there is a single semantic interpretation of the requirement
- **Traceability** – permits unambiguous requirements traceability in design and verification
- **Verifiability** – the requirement is such that (1) its satisfaction in the design is verifiable, and (2), its satisfaction in the implementation is verifiable
- **Singularity** – only one actor, one action and or one object of action per unit of time
- **Feasibility** – some means of satisfaction exists
- **Non-Redundancy** – not duplicated within the set of requirements

From Square Kilometre Array Systems Engineering L1 Requirements Analysis Guidelines. Private notes, January 2014.

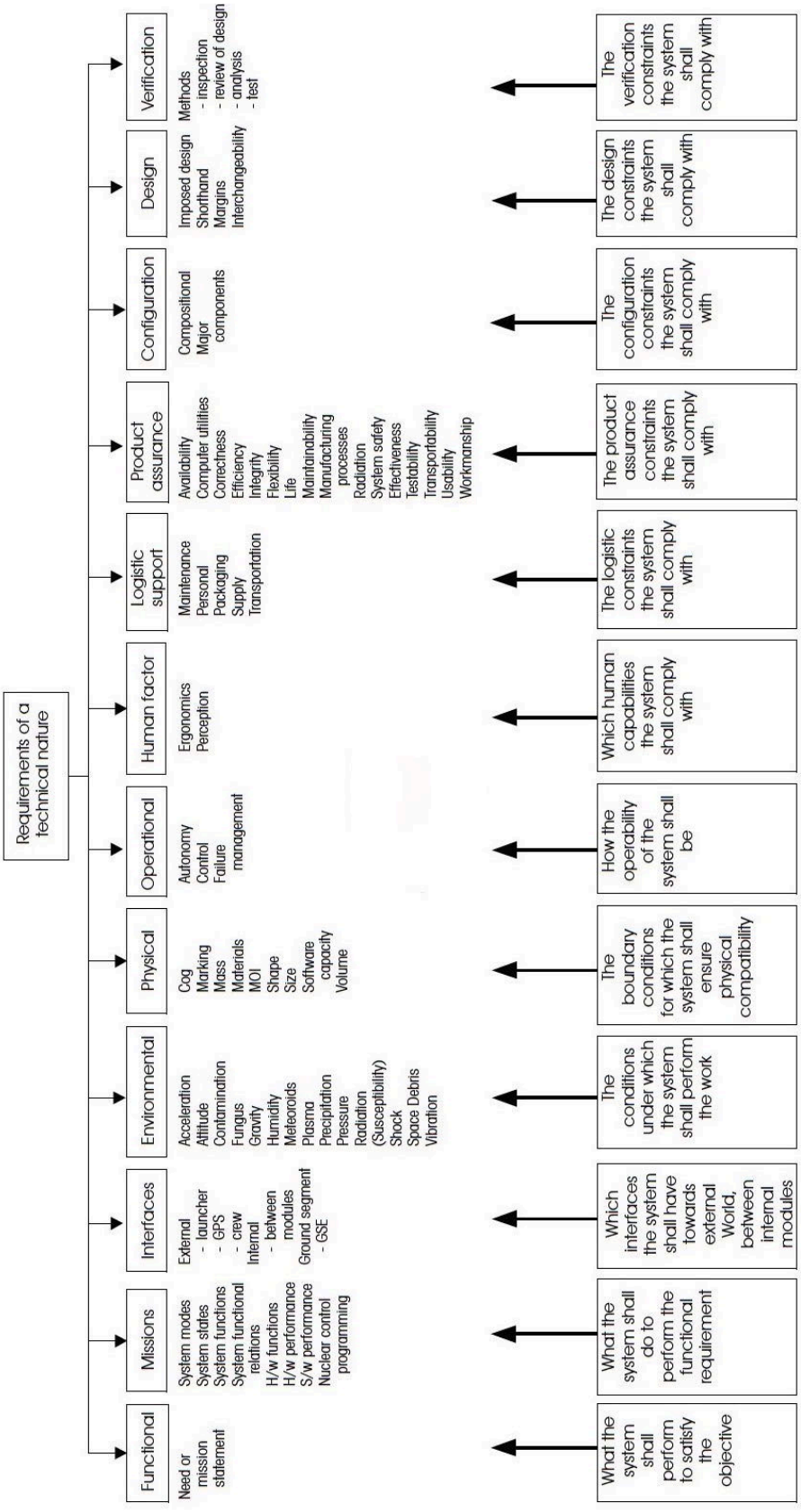

Figure 3.4: *ECSS space system requirement types (ECSS-E-10-B).*

When considering applications using space-derived data, what we have in mind is *information* delivered to an end user. Modern software development does not distinguish strongly between design, development and deployment. What does this mean in terms of user requirements? If there is no well-defined path from initial user requirements through to design, development, then culminating in deployment as in the typical engineering-style waterfall model, how can a project ever be said to be done and how can commissioning take place? The answer is that software development proceeds cyclically and iteratively; perfection is not sought, and 'done', and is a matter of contractual agreement not bound to the validation and verification of requirements. This is quite a different scenario to space engineering, despite the earlier assertion that there is an increasing amount of software in satellite design.

Ralph raises philosophical problems with requirements worth exploring, since these are critical to the entire space mission design. His two principal objections are ontological and epistemological. There is a third, which is that the engineering approach is altogether missed by many software development enterprises, which adopt a more fluid approach, even where architectures for design and development are taken very seriously.

His ontological challenge points out that where there are many approaches to achieving a goal, there may be insufficient overlap between approaches to form solid requirements. This holds true where there is a relationship between *features* and requirements. Most engineers are trained to think in terms of functions, whereas a feature can be an attribute which does not contribute towards a goal in and of itself. Ralph puts forward this definition of a requirement in relation to a goal: 'A requirement is a feature of a design object that is necessary to achieve a goal' and yet even given this definition, a software object may contain many features which do not substantially contribute towards any goal.

Requirements do not form the mainstay of design for most software projects. Software is not designed according to requirements per se. Attributes have gained more prominence, and the Software Engineering Institute now espouses Attribute Driven Design and other methods over the Waterfall Model (see below).

An entire space mission is predicated on the correct gleaning of requirements. A mass of work is in place to ensure that the design and eventual deployment meet the requirements specification. In most scenarios in the space industry, this requirements specification has been arrived at in consultation between client and engineering company, and that client is often government or an intermediary representing government. Requirements are often narrowly defined in terms of a particular operation, and those in government specifying the requirements are often themselves engineers.

This scenario contains several problems:

1. It misses the user applications arena
2. There is a large time lag from initial consultations with users to design and deployment.
3. The eventual end user of space-derived data is sometimes unknown and unanticipated at the time of space mission design. This means that the data type may not be commensurate with the needs of users.
4. Users as defined in the space mission are frequently not end users, i.e. those who will actually use the data at a computer or, increasingly, mobile phone.

When the space engineering design and development models were defined, mobile platforms were not yet invented, and the business of getting an object into space so complex, risky and expensive, that strict boundaries had to be drawn around what constituted the space industry. Retiring risk is the chief focus of the systems engineering approach in the space industry.

Figure 3.5 shows the relationship between user requirements (in this case termed ‘expectations’) and an eventually designed EO system. This is an ideal model, and describes a system in which the customer and the end user appear to be coterminous. An engineer would see no problem with this model, and could locate it within the normal systems engineering framework. Engineers believe their method to be rational, and may not agree with the assertion by Lin and Silva (2005) that:

'… the management of the adoption of information systems is a social and political process in which stakeholders frame and reframe their perceptions of such systems, and that social phenomena such as language, symbolic power, and communication processes should be seen as fundamental for understanding how these technological interpretations are framed' (Lin & Silva 2005).

Engineers who are not schooled in the social sciences may not concur with the notion that any systems engineering framework is the product of a social and political environment. Most engineers would however agree with the observations of Alenljung and Persson (2008), that requirements engineering is not a science and inherent in it are: 'ill-structured problems, uncertain, dynamic environments, shifting, ill-defined, or competing goals or values, ambiguity of information, interpretation of the history of decisions', and to add to this list they identify time stress, high stakes, multiple player situations, and organisational goals and norms. (Alenljung & Persson 2008).

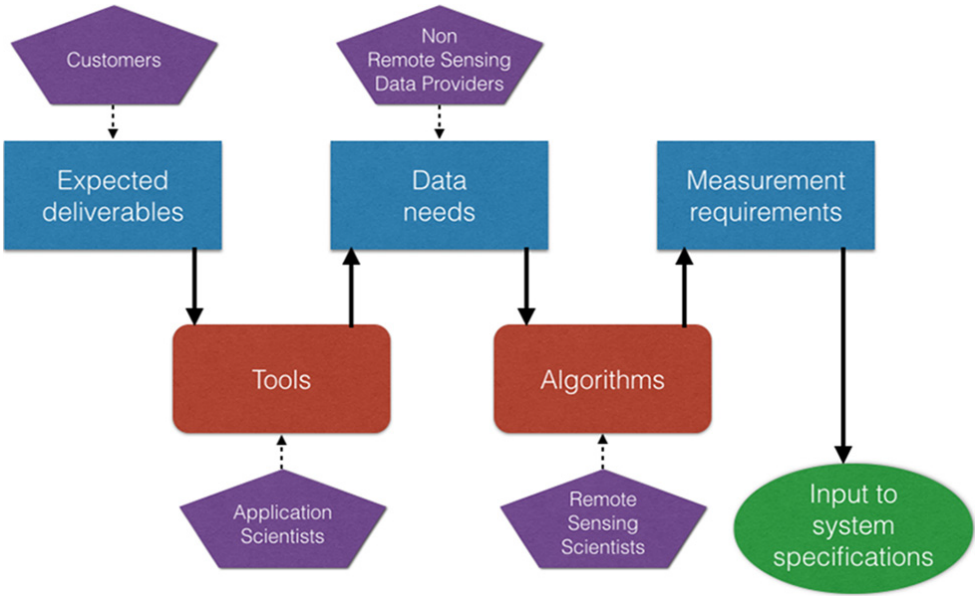

Figure 3.5: *Schematic representation of the process involved in converting users' expectation into measurement requirements (Verstraete et al. 2015).*

Requirements are not elicited in a politically neutral environment. What many researchers are saying is that requirements engineering is highly contingent. It takes

place within a specific socioeconomic, historic and political context. In particular, as Milne & Maiden (2012) point out, 'power and politics have necessarily become increasingly relevant factors, but that they have not yet been given adequate consideration.' In satellite engineering, it takes place within the norms and practices of a space industry whose focus is designing and constructing space technology, not creating end user applications. Others go further, attacking the very philosophical underpinning of requirements elicitation (Ralph 2013).

Verstraete et al. (2015) would agree with this, exhorting the panoply of different specialists within the space mission design chain to communicate with each other and not lose sight of customer expectations. He underscores the importance of user requirements in this chain:

> 'Failure to collect or misinterpreting user requirements will lead to a perception of an overarching technology push, which may be resented or rejected by the government or the funding agency; while minimal involvement from industry or suppressed inputs from the scientific community will inevitably lead to the definition of a run-of-the-mill, uninspiring, solution that duplicates existing capabilities and therefore may not even be useful.' (Verstraete et al. 2015).

Why Verstraete et al., seasoned professionals in the space industry, feel the need to state this is interesting and pertinent to the argument presented here. Since the traditional systems engineering method employed in the space industry places requirements at the start, and all technical specifications flow from this, what could be the problem? It is worthwhile examining the practices of the adjacent computer industry. If we see satellites as computers within an Information Systems (IS) value chain, there may be some interesting similarities between these industries.

3.6 Enterprise architectures and the user concept

Bridging engineering and the business and software worlds are Enterprise Architectures. These arose out of business systems planning as early as the 1970s, though Zachmann is often credited with having kick-started the topic with his Zachmann Framework tool in 1987.

Some Enterprise Architecture frameworks were devised for space engineering, including one of the more popular enterprise architectures today: TOGAF, The Open Group Architecture Framework. Although TOGAF was initiated in the 1990s, its origins lie in the Technical Architecture Framework for Information Management. TAFIM was developed from 1986 until 1999 by the US Department of Defense (DoD), and in parallel in 1994, the DoD started the development of the C4ISR Architecture Framework. This in turn evolved into the Department of Defense Architecture Framework (DoDAF).

One of the key features of TOGAF is its cyclicity. Although there are blocks of activities identified within the TOGAF framework, in fact it is legitimate to take up work at any point in the cycle. For this reason, the standard image of high-level TOGAF architecture development is of a series of circles in a daisy formation, with Requirements Management as central to all activities (see Figure 3.6).

The enterprise is itself not necessarily one company, or even an industry model such as will be familiar to those working in EO. It is, as defined by the standard TOGAF 9: 'The highest level (typically) of description of an organization and typically covers all missions and functions. An enterprise will often span multiple organizations.' (Josey 2011). The enterprise value chain ends at the end user, and therefore naturally encompasses end user applications or programs which arise as a result of any project. The TOGAF Framework is not a tool brought in to manage a specific time-bounded project, such as a space mission, but is a blueprint for sustainability for an organisation.

Requirements Management as a block of activities is weakly described in TOGAF. Its defining feature is that there is no concept of a static set of requirements '…but a dynamic process whereby requirements for enterprise architecture and subsequent changes to those requirements are identified, stored, and fed into and out of the relevant ADM phases, and also between cycles of the ADM' (TOGAF Version 9.1). The ADM is the Architecture Development Method, which is the core of TOGAF and shown in Figure 3.6.

Requirements are ever-changing because the environment is dynamic: 'architecture often deals with drivers and constraints, many of which by their very nature are beyond the control of the enterprise' (TOGAF Version 9.1). Therefore the entire cycle of activities is predicated on a changing set of requirements. Creating objects in this milieu, to engineers who need to get around to a Bill Of Materials at some point, would appear to be implausible. However the ADM has been created in order to allow the architects to create complex abstract entities which only at the last moment become concrete solutions. This large disjuncture between design and physical object characterizes large-scale architecture undertakings in the business and software world.

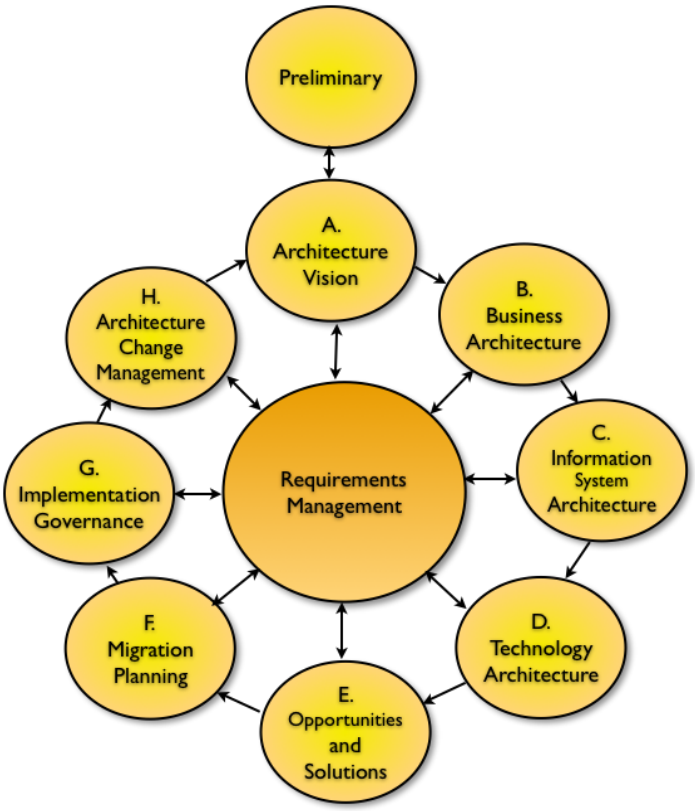

Figure 3.6: *Architecture Development Method* (TOGAF Version 9.1).

The Requirements Management process does not concern itself with how requirements are managed. It does not deal with their creation, disposal, or prioritisation. Requirements are simply held in a Requirements Repository and variously selected for the different stages of the ADM. As would be expected with any engineering undertaking, both functional and non-functional requirements are

applicable, but in addition to the requirements themselves are the environments in which those requirements play out. The architect must take account of the requirement's assumptions, constraints, domain-specific principles, policies, standards, organisation guidelines and other specification norms.

TOGAF further doesn't supply any processes or tools for requirements management, simply stating what an effective requirements management process should achieve. As TOGAF 9.1 states, the field of Requirements Engineering provides plenty of advice in the specifics of requirements themselves, and TOGAF doesn't see the need to interfere.

One of the guiding Application Principles in TOGAF (Principle 16) is Technology Independence. Technology is subject to continual obsolescence and vendor dependence. These must not become the drivers over user requirements. Engineers on the other hand are trained in technologies and their designs are very often driven by what technology is available, and, in space, has flight heritage. This is one way in which TOGAF would be difficult to apply to many space missions unless this principle were deliberately disregarded. However the main thrust of the TOGAF approach is to create architecture designs which are distant from solutions and technologies. This indirection is vital to the success of applying architecture frameworks.

Over the past two decades, the US space industry has had to adopt The Department of Defense Architecture Framework (DoDAF) as its architecture methodology. This is presented in its most procedural and simple form in Figure 3.7, where technologies, particularly data technologies, are early targets for analysis. The chief criticism of DODAF and many architecture frameworks is their heavy-handedness. Weighty volumes describe their processes and approaches which require several training courses and changes to established business processes within organisations to adopt. In the meantime, while large organisations are getting to grips with architecture frameworks, disruptive technologies are poised to steal their thunder.

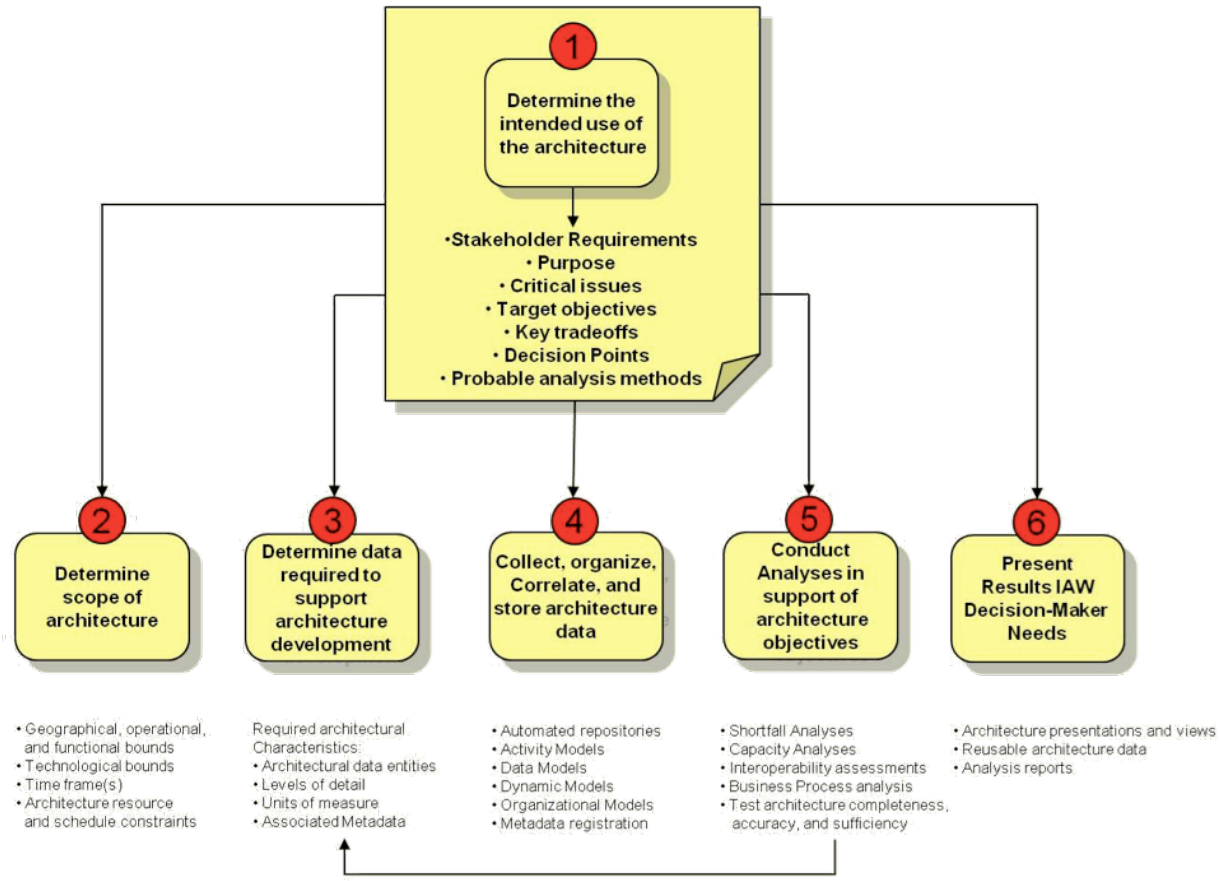

Figure 3.7: *DODAF 6-stage architecture process Department of Defense Architecture Framework Version 2.02.*

It is worth mentioning lighter-weight architectural approaches designed for software development, which take ideas from systems engineering and apply them more appropriately and with a far less time and cost overhead. The Software Engineering Institute (SEI) is a sound repository and generator of these software-oriented approaches.

The SEI's ATAM (Architecture Tradeoff Analysis Method) and ADD (Attribute Driven Design) both attempt to isolate what is germane to software development projects, and focus on tools and techniques to assist the architect in devising and communicating their work. They emphasise iteration and re-use, and designing not according to requirements per se but attributes.

The ADD method is for software-intensive projects, and deals specifically with these challenges:

- How do you design the architecture for a system so that it best meets users' needs?
- How do you meet quality attribute requirements for envisioned systems?
- How do you determine which architectural strategies are appropriate for your quality attribute requirements?
- How can you understand the impact of quality attribute tradeoffs while you're designing a software architecture?

http://www.sei.cmu.edu/architecture/tools/define/add.cfm

In Attribute Driven Design, the key tool is workshops that elicit what Quality Attributes are required by a given architecture. These attributes can be ranked and the chosen architectures analysed against them, or created for them.

The Architecture Tradeoff Analysis Method shown in Figure 3.8 is a technique for comparing architectures and their fit to attribute-driven goals. Several different architectures are normally proposed according to the agendas of different stakeholders. The ATAM provides a way of comparing these according to an agreed set of attributes.

Figure 3.8: *A conceptual flow of the Architecture Tradeoff Analysis Method Software Engineering Institute. (www.sei.cmu.edu).*

The question is whether these very different approaches to architecture and design incorporate the user in different ways, or allow for a different user concept, and how do they fit with systems engineering in a satellite design project? Although some of

the design concepts in software architecture may be very familiar to engineering, there are also some important points of divergence.

In their general approach to architecture, the SEI states that it is not necessary to produce comprehensive documentation and diagrams to cover every stage. They are moving away from two major entrenched engineering notions: that of hierarchical levels, and the idea that everything must be documented. Engineers used to regarding all design as situated in a hierarchy often have difficulties with software development for these reasons.

The SEI states that it is only necessary to produce those views that are necessary for a particular purpose (Clements et al. 2010). Engineering tools (such as the widely used CORE system) typically generate comprehensive diagrams covering every aspect of a design. Specific diagrams or views can be generated from an all-encompassing master repository containing all items, functions, interfaces, requirements, products and all other engineering artefacts. This is not the approach taken for much software development, where 'levels' are often disregarded in favour of objects relating to features, and only a small subset of the design is documented.

What is emerging from this analysis is that architecture frameworks and design methods are chosen to fit the task at hand. Traditional satellite engineering entails a great many actors and stakeholders in the space value chain, and a complex architecture framework is required to characterise the whole enterprise. Although software engineering, or the creation of large-scale software programs to perform a variety of complex tasks, may also entail many actors, the core algorithms will be developed by a few individuals.

A satellite project is, in fact, a one-off undertaking. It is a mission with a linear trajectory, requiring a particular approach to design and construction. Space also presents certain physical constraints, and a sizeable portion of a space project involves hardware, which unlike software is inflexible, and where decisions regarding hardware characteristics must be taken fairly early in the design cycle. Architecture frameworks designed for business and information systems can be essentially cyclic, sustainable, and contain many re-usable components. These approaches are not

mutually exclusive, and neither precludes a particular treatment of the user. What is more germane is that the space industry operates within a particular paradigm and set of expected outcomes, ontologies, and practices, and that these have not changed for many years. As shown with reference to the standards and reference models used by the space industry, these do not treat the user in any sophisticated way, and user requirements are one set of requirements among many others and not paramount in terms of the perceived success of a mission. Plus, as the space industry further commercialises and moves out of the influence of government, different models and *modi operandi* are possible.

4 Disruptive technologies

Because the space industry, like many others, operates within its own confines, is risk-averse, slow to change, and not traditionally driven by consumer markets, the cycle of disruptive technology innovation has not featured as part of normal technological change management processes in the industry. By contrast, in the IT industry major disruptions in the relationship between technology and markets are commonplace. Disruptive technologies are interesting to explore in terms of developing countries, since they represent new approaches that do not rely on entrenched *modi operandi*. Just as mobile telephony could 'leapfrog' landline-based telephony and gain serious purchase in developing countries, where the fastest market penetration was witnessed (United Nations 2009), so too there is potential for new disruptive space technologies to be adopted by space industries and agencies outside of the developed world.

While conservative in nature, the military is aware of the effects of disruptive innovations, as illustrated in the following quote from a 2012 military report:

> Disruptive change is not a new phenomenon. New technologies, unexpected threats, novel tactics and techniques, and altered approaches can create changes to the strategic environment in which we operate. Those changes can alter the landscape in ways that, if not addressed, can dramatically upset the existing order. They can render effective strategies impotent, change winners into losers, and turn victory into defeat. (Pawlikowski 2012)

Pawlikowski cites the common example of disruptive change in the music recording industry with the introduction of digital music in 1982, pointing out that the disruptive force can take a long time to play out, and that such disruption is not necessarily deleterious for the industry being disrupted. It can be, and in her example has, left 'many big music labels grasping for how to cope with the threat.'

Disruptive technologies arise to challenge an industry status quo, overturning established cant, and addressing a need in a better way. This new way can upset existing power structures. As remarked by Kostoff et al (2004): 'Disruptive

technologies create growth in the industries they penetrate or create entirely new industries through the introduction of products and services that are dramatically cheaper, better, and more convenient.' They introduce both threats (to established industry) and opportunity (for newcomers, and eventually for some established organisations). Disruptive technology theory however cannot be applied to every industrial sector in the same way, as there are important differences.

In a normal competitive environment characterised by increasing technological complexity, the progress and adoption of new technologies, and the entire business of innovation does not follow a linear pattern. Technologies are adopted not according to what is expedient, rational, or cost-effective but along a complex and messy relationship between society and technology, politics and marketing. At its most sterile, the introduction and success of disruptive technologies follows a model akin to Marxist dialectics, or more appropriate for technology and science, a Khunian structure of scientific revolution. Those technologies which are now dominant and promoted by established organisations become overturned by an innovative newcomer which threatens and destabilises the organisational, market, and technical status quo. This in turn becomes the established leader.

A working definition proffered by van der Veen et al is:

> 'A disruptive technology is a technology that alters the status quo of both the market position of the dominant technology and the competitive market layout by having an alternative perceived performance mix, which is valued more by the customer than the one of the dominant technology' (van der Veen et al. 2012).

A key commentator and researcher on disruptive innovation is Prof C M Christensen who, along with others, has identified sustainability as being a vital factor in assessing its trajectory, mechanics and impact. Figure 4.1 shows the relationship between new entrants and incumbents, and crucially that the trajectory of technological progress outstrips the ability of customers to take up those improvements. Markets and customers' ability to take up new technology lag behind the technologies foisted onto them by the space industry.

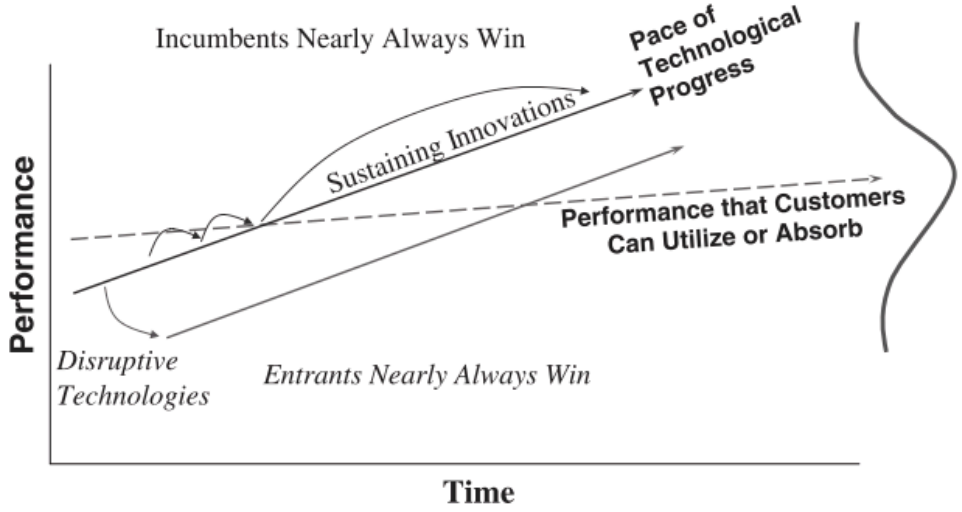

Figure 4.1: *The constructs of performance trajectories and the classification of sustaining and disruptive innovations* (Christensen 2006).

There is a second type of disruption which can occur, called 'low-end disruption', where a niche technology can come to serve a mass market, and thus becomes itself a mainstream technology, as described by Christensen, Anthony, and Roth (2004) quoted in (van der Veen et al. 2012). Both of these are prevalent in the space industry and have implications for developing countries and their relationship with space technology. These modes of disruption also have an interesting relationship to the user, who becomes a more central driver of change in a disruptive model.

4.1 Comparison of disruptive technologies in the space and IT Industries

The space industry began to be aware of the encroachment of disruptive technologies more than twenty years ago. At that time, the environment of space engineering was characterised by a bloated and unsustainable status quo, explained by Maj Gen Thomas Taverney: 'with the Space Acquisition Vicious Circle, our space systems become more and more complex and expensive, with no room for failure.' Figure 4.2 shows how one feature exacerbates the next, resulting in tardy and very expensive

satellites in increasingly fragile constellations. Although he was concerned with satellites for military purposes, the same holds true for non-military functions.

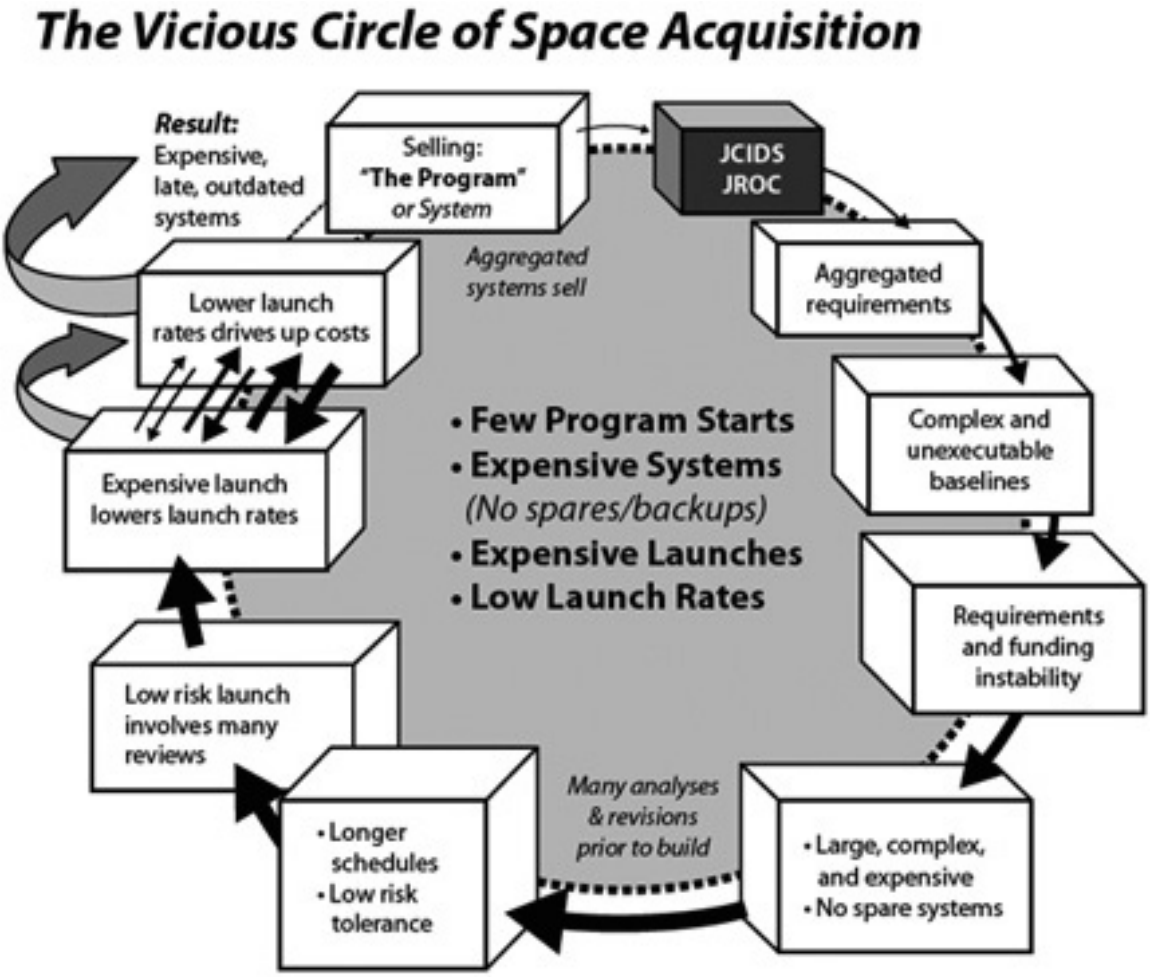

Figure 4.2: *Resilient, disaggregated, and mixed constellations* (*Taverney 2011).*

In addition to a complex and expensive design and development cycle, two other characteristics of space made it ripe for disruption: risk aversion, and a lowering of barriers to entry. In Earth Observation for example, customer needs and technical performance are both trending towards higher spatial resolution and shorter revisit time imagery (Denis et al. 2016), and both can be supplied by a variety of providers who do not belong in or arise from the traditional space industry. The reason other providers have joined this market is because they are able to undermine or bypass space industry norms. These facets will be explored further below.

Space and satellite technologies and how they face disruption are not identical to the IT world, where disruption has been a commonplace feature, and where companies

seek to disrupt themselves in a normal cycle of constant competitive inventiveness. A typical story about Steve Jobs goes that, when introducing the iPhone to the Board of Directors at Apple Inc., he was criticised as the iPhone could potentially supplant the highly successful iPod. His retort was that overturning their own product markets was exactly what they should be doing.

It is more normal for disruptive technologies to be introduced by outsiders, and for there to be an initial period of market scepticism prior to their exponential rise. Theories of disruptive innovation have one common feature: that of a sudden takeover of a technology which supplants existing solutions. Most theories take their data from the digital world, and since space technologies are frequently digital, this is a further reason they have been subjected to disruption in recent decades.

A significant difference is that space is one of the global commons along with sea and cyberspace, and these have strategic significance. Therefore there are reasons for governments to take an interest besides the military applications afforded by space. Cebrowski and Raymond (2005) point out that space, sea, and cyberspace constitute a 'triad of capabilities on which America's global power rests'. They see 'falling barriers to competitive entry and increasing technical vulnerabilities in space systems, coupled with increasing dependency on space capabilities' as heralding a need to refresh business models with respect to space technologies:

> 'While the cost to place a kilogram of capability on orbit remains expensive, the capability resident in every kilogram is soaring, given the unrelenting increase in information technology' (Cebrowski & Raymond 2005).

As space technologies move increasingly into the commercial realm, governments too must refresh their ideas about how to construct and operate the objects they send into space. Here lies a complicated relationship between cost, capability and risk which stresses the traditional structures of the space industry, further exposing it to disruption.

4.2 Complexity, risk, and cost: fractionated architectures

A solution to risk in space engineering is to introduce redundancy, such as parallel systems for mission-critical components, and to insist on flight heritage. Both these responses can increase cost, development schedule, and therefore increase market risk as well as, paradoxically, increase complexity and thereby technical risk. As Eremenko and Hamilton point out:

> 'The current approach – or lack thereof – to designing space systems for robustness to uncertainty is the key to the sharply escalating costs and development timelines facing the space industry. Consider, for instance, the typical status quo approach to making a spacecraft robust to technical or environmental risk. The solution is adding margins or parallel redundant component strands in mission-critical areas. This addition of components, in turn, increases system complexity. As complexity grows, so does the system size, cost, and schedule' (Eremenko & Hamilton 2008).

This introduces a 'cost-complexity death spiral', and approaches to address this in the space and aerospace industries have been to opt for adding capabilities to satellites, making them more attractive, but also increasing complexity and fragility. The reasons for this, postulate Eremenko & Hamilton, are to do with organisational inertia or aversion to bearing the risk associated with *process* changes (Eremenko & Hamilton 2008).

Their proposed solution to the death spiral is to create a 'fractionated space industry'. What this means in practice is that different organisations deliver modules or components that can be increased or decreased in number as the need arises. A spacecraft's exact capabilities do not need to be designed *ab initio* but can be manipulated closer to launch. Fractionated architectures bring flexibility to adapt to changed circumstances in demand. The closer to market delivery a satellite's output is, the lower the risk that it will not deliver in accordance with demand,

This rule may hold true for many applications, but the usual market forces do not always apply with satellite data and satellite applications. Nobody demanded Uber, for example. Herein lies a similarity with the IT industry and a glimpse into the

rationale behind ‘user-disdain’. Users, particularly end users, are insufficiently technically proficient to make demands on these industries. Therefore the normal economic rules of supply and demand do not apply. Products with a highly technical basis are driven by ‘technology push’ scenarios, where the drivers for product development are technological innovation and not market demand.

However, Eremenko and Hamilton are arguing for a modularised space industry and satellite design as opposed to the few large organisations that have tended to dominate particularly the large satellite market. They point out the analogy with the IT industry, where corporations producing monolithic mainframes became obsolete. They are not quite correct in this, particularly now with the advent of Big Data requiring High-Performance Computing. The term ‘mainframe’ may have slipped from popular use, but large computing facilities are re-emerging given the requirement for massive processing and storage capacity. Plus, after an initial shaking out, some large actors, such as IBM and Hewlett-Packard, have persisted. This does not diminish the impact of disruptive technologies, and those large companies that have persisted through many cycles of innovative disruption have had to adapt to constantly changing market demands.

Time delays introduce their own inherent risks, as Pawlikowski (2012) describes:

> ‘…spacecraft planned for construction in the next decade are still using computer processing technology from the late 1990s when they were designed. For example, some billion dollar satellites launching in 2020 will have missed over 24 years of capability increases driven by Moore’s law, or roughly 16 cycles of processing power increases’.

Retired engineers need to be consulted regarding obsolescent systems they had been working on, but which have ‘flight heritage’ and are therefore considered low risk, and still being commissioned for space missions. Although it is the case that repairing machinery in space is almost impossible, and that mistakes can result in catastrophic failure, it is also, in the terrestrial realm, highly risky to unleash new technology on the public which is replicated millions of times. The Samsung Galaxy Note 7 debacle in 2016 is a case in point, where batteries overheated and sometimes conflagrated,

requiring a recall of 2.5 million units with a significant dent in reputation (CNN website, 2017). The risk of this type of failure does not inhibit Samsung's IT industry from innovating both in terms of its products and processes.

As Pawlikowski remarks, the space industry may adopt new technologies from time to time, but its underlying methods and design processes remain static:

> 'The uses, importance, industrial base, cost dynamics, complexity, and competitiveness of space have all fundamentally changed from where we began; but the trajectory of system architectures did not change with them—rather, they continued on their original path' (Pawlikowski 2012).

Five years ago it was pointed out that the space sector had not yet been 'commercialised' and that if more were invested in disruptive technologies, there would be a flowering of more commercial space offerings in the fields of '… earth observation, telecommunication & navigation while possibly opening it up to new ventures such as space tourism, space based solar power and asteroid mining' as this commercialisation would result in higher performance and lower prices (van der Veen et al. 2012).

4.3 Technology and regulatory barriers to entry

Cost and strategic/military barriers to entry have maintained strong boundaries around the tasks of the aerospace and defence industries. Underpinning space mission design for some space agencies and governments are protectionism and control, as seen with the example of ITAR restrictions. Launch and infrastructure costs remain high. These are factors which have begun to be eroded to some extent, with the advent of cheaper and expendable CubeSats.

Planet are, at the time of writing, busy disrupting the EO market sector. In February 2017 they launched a swarm of 88 small satellites each with a mass of around 4kg, on a single rocket. On their webpage whose title is 'Agile Aerospace' they state:

> 'Planet is designing, building and launching satellites faster than any company or government in history. We use commodity consumer electronics to build highly capable satellites at drastically lower costs. With the most advanced

> satellites launching into orbit every 3-4 months, our capabilities are on the cutting edge and always advancing' (Planet website, 2017).

This is not a one-off endeavour by a small company, but linked to Google's long-term strategy. Google sold its satellite company, Terra Bella to Planet in early 2017, and entered into a multi-year contract to allow Google Earth access to Planet imagery. Terra Bella was formed following Google's purchase of Skybox Imaging for $500 million in 2014.

SpaceX plans to launch 4,425 satellites to provide Internet connectivity to the entire world. Samsung and Boeing also have similar plans to launch thousands of small satellites. These may be relatively expendable and offer relatively low resolution, but their characteristics have been driven by market analysis, and entailed jettisoning the normal low-risk high-tech approach of space engineering.

An analogy exists with the IT industry, where in the early days up to the 1980s, computers were large, very expensive, technically difficult and the province of institutions that held specific data requirements. The advent of ever cheaper and more powerful personal computers saw an explosion of applications, especially after technological inhibitors were reduced, with more user-friendly and affordable development environments, the Internet and so on. Specialist knowledge, gatekeepers, and technologies became increasingly accessible to the general public and entrepreneurs, who took advantage. Whether newcomers can *sustainably* attack traditional space actors and established business models, and whether disruptive technologies are merely smaller, faster, cheaper is discussed below.

4.4 'NewSpace' business models

Along with many commentators on disruptive technologies, Cebrowski & Raymond quote Professor Clayton Christensen's Disruptive Innovation Model, describing a 'new value network' as being created by smaller satellites (Cebrowski & Raymond 2005). Small satellites, in particular CubeSats and nanosats are typically associated with disruptive technologies in space, or as it is often called 'NewSpace'. Its early moniker, reflecting a naming convention in the Unix operating system, was 'alt.space'

(alternative space), 'alt.*' being the prefix for newsgroups self-classified as 'alternative', often in a political sense. Small satellites are cheaper and faster to develop and are *being thought of* as expendable market-driven platforms.

What is alternative about the EO business models of the past seven or eight years is that they have emerged from the military and government sector into commercial and private domains. This is for several reasons, all contributing to recent and ongoing major disruption in the field. The new value network lies in the creation of a mass market for space-acquired data both in remote sensing and navigation.

Increased performance of commercial satellites has a high degree of convergence with defence needs (25-30cm resolution being the current benchmark). Until recently, this performance was only affordable for governments and large established entities. The disruptive NewSpace trend in EO involves a model of start-ups and big web actors (e.g. Skybox and Google) with massive investment capacity, mirroring the rise of Silicon Valley in the 1980s, and often located there. International newcomers, investing in their own EO capacity, have joined the big established actors, opening up new opportunities for international or regional cooperation which may bypass the established industries and governments entirely. In parallel, development of the Internet has increased mass-market interest in geo-information. This context was favourable for cross-fertilizing space EO imagery with the digital economy, paving the way to new businesses and services (Denis et al. 2016).

4.5 Sustainable space markets for EO data

As pointed out by Denis (2016), Moore's law cannot obtain in low Earth orbit. Moore's law is often quoted in the IT industry, whereby the density of integrated circuits doubles every two years. The exigencies of gravity, Kepler's law and Rayleigh's criteria mean that a non-geostationary object in space cannot fly at low altitude and stay there without expending energy, and cannot stay overhead in a stationery position. This caps the revisit time for a satellite. On top of that, the resolution of any imaging system is limited by diffraction: for a given wavelength, the angular resolution is inversely proportional to the aperture of the instrument (Denis et

al. 2016). A large imager which can take high resolution pictures needs a large satellite, as shown in Figure 4.3.

Although the mass of imagers has decreased and new technologies on the drawing board promise even more lightweight imaging capabilities, for now an expensive constellation of satellites is needed for any comprehensive EO programme, which requires an extensive ground station network to service it. This infrastructure is non-trivial and requires significant investment, which is out of the question for a start-up. Partnerships in this field are mandatory. There are technical barriers concerning payload size, if the trends continue with demand for spatial and temporal resolution continuing to rise. A new project by Airbus is addressing this demand in an innovative way, and this is mentioned below.

A sustainable market implies ongoing profits, and as in the early days of the dot com boom, new entrants to the space arena are not yet profitable. At some point investors pull out, according to classical business cycle dynamics, leaving a few successful companies to become the dominant leaders. As with the IT industry, most start-ups do not succeed sustainably. However, while they encroach traditional markets with their innovations, they disrupt and bring changes which, as we will discuss in Chapter 5, may hold benefits for developing countries.

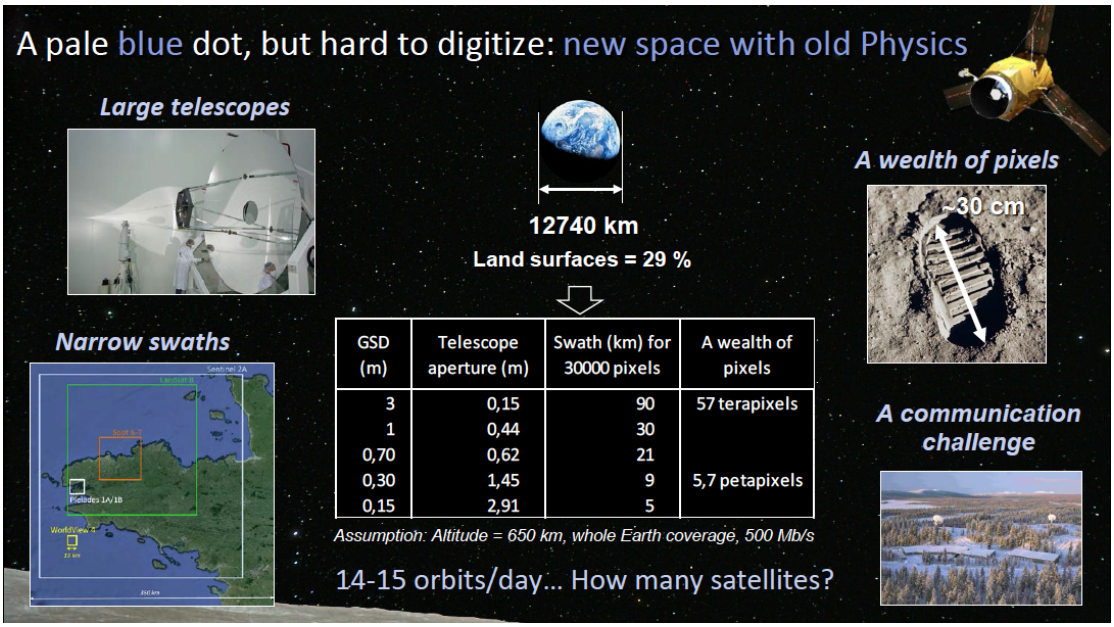

Figure 4.3: *New space with old physics.* (Denis et al. 2016).

Remote sensing is not yet a profitable endeavour. The European Space Agency has decided to operate Sentinel satellites and provide their data as a public good because they could not find a significant commercial market for their imagery. By all accounts mass utilisation of commercial remote sensing data remains a relatively new enterprise, with rapidly changing technology offerings and marketplaces.

4.6 Current disruptors

Disruption in the space sector is not all about small satellites. As far back as 2004, student-built spacecraft projects had been popular already for 10 years. Their main outcomes were training and access to space for university researchers. However university satellites have not disrupted industry practice in favour of small spacecraft (Swartwout 2004). As he points out, with a few exceptions, university-built spacecraft have been low cost, low capability and marginal performance vehicles. Furthermore the academic calendar forces missions into being of short duration. The tremendous reduction in component cost means that universities can indulge in high-risk, high-reward missions, because of their great tolerance for failure. Therefore universities can regard spacecraft as disposable. This is not a sustainable model for business.

The high visibility and prevalence of nanosat missions (between 1 and 10kg mass), both from the university sector and some major and highly publicised disruptors such as Planet and SpaceX, has meant that often these missions are thought of as coterminous with disruptive innovation. There are a few other technologies worth mentioning which are also disruptive to the status quo.

SpaceDatahighway is the name for a project launched by Airbus: an ‘innovative inter-satellite laser communication technology on-board the lower orbiting satellites or the aircrafts and on the geostationary satellites that are permanently in view of (European) ground stations.’ (Airbus Defence and Space website, 2017). The implications of this technology are near-real time EO video, and ‘radio-silent’ operations for increased stealth and security for European institutions. This ultra-broadband technology eliminates data latency, has a data rate of 1.8 gbps, and can transmit 40 terabytes per day. This does not deploy nano- or micro-satellites, but

combines technologies and large geostationary satellites to provide a potentially disruptive technology. Interestingly this is a technology push initiative, and Airbus is seeking applications for their technology.

Aerostats are encroaching into EO territory by offering several capabilities unavailable to satellites, and at lower cost and risk. These tethered helium balloons can sustain continuous monitoring of land area with high resolution video. Weight is not as problematic as it is for satellites, and fibre optic cable running down the tether obviates the need for ground stations. Sophisticated aerostats can remain in place for a month without requiring maintenance, and once adjustments are made they can be easily released back to their monitoring position. Being situated beneath clouds increases their functional capability.

Aircraft are expensive to operate, and drones are prone to failure and can only monitor a small swath. Nevertheless these alternatives to satellites for EO applications are being deployed and further explored in developing countries where satellite revisit times are relatively lengthy, and coverage relatively poor. High altitude systems which do not require launch into space are cheaper, less risky, more local and responsive to demand. As more of the world's population moves into cities, this becomes a strategic problem for sales of EO imagery and satellites, as there are alternative vehicles to satellites that can be established closer to centres of population.

Large satellites can also act as disruptors. High Throughput Satellites (HTS) which, as the name suggests provide high bandwidth and low latency, threaten geosynchronous satellite services. HTS satellites, launched in the last few years by several of the space industry giants (Eutelsat, Inmarsat and Intelsat amongst them) have fibre-like data rates, and can deliver 4G type services to remote rural locations, as long as they are located within 45 degrees of the equator. HTS satellites are costly, given the complex multi-beam payloads they are carrying, which enable them to re-use frequencies. These drive the cost up, and an extensive new ground infrastructure is needed to operate them. However, there is increasing demand for broadband IP services justifying the expense. These could prove more disruptive than LEO satellites. More work needs to be done to explore this area.

An interesting disruptor to the normal business model for satellite communications is discussed in Chapter 5, where satellite-enabled Internet access and cellular hotspots are provided by units attached to soft drink dispensing machines in developing country rural areas. This initiative is a partnership between Coca-Cola South Africa, local bottling partner Coca-Cola Fortune, and BT Global Services.

4.7 Renting data

The traditional model for EO imagery is for customers to purchase images of increasing resolution for their specific purposes (disaster management, soil analysis, coastal erosion monitoring etc.). Many of these images are inserted into geospatial software applications, and customers are expected to have their own specialists who can manipulate this data. Recent changes show an increase in image rental, where customers do not need to download images but wish to have a glimpse at a solution within a vertical application. Many customers are not as interested in high spatial resolution as high revisit times, and their applications frequently need a mix of technologies to get around cloud cover. Their need is for information and solutions, not datasets.

What customers are increasingly seeking is complex analysis where data has been sourced from a wide range of providers, locations, and types. These arise from synergistic technologies, where the sum of its whole is greater than the simple sum of its parts.

4.8 Synergistic Technologies, Big Data, the Internet of Things

Social, Mobile, Analytics, Cloud (SMAC) relates to:

> ‘an ecosystem that allows a business to improve its operations and get closer to the customer with minimal overhead and maximum reach. The proliferation of structured and unstructured data that is being created by mobile devices, sensors, social media, loyalty card programs and website browsing is creating new business models built upon customer-generated data.’ (Techtarget website, 2017).

Many customers of remote sensing data no longer wish to buy expensive images, but are looking for processed and analysed information embedded within a framework which addresses their need and speaks their language, in a format interoperable with other forms of data. This data originates from many sources as the term SMAC implies. With time, this data will be augmented by 'the Internet of Things' where a proliferation of devices includes sensors that send data via the Internet to data processing and analytics centres. The sheer amount of data anticipated requires (what in today's terms is) High Performance Computing along with the current buzzword: Big Data.

This is important for space technologies and remote sensing, not just because there will be an increase in Internet traffic when billions of new sensors become active, but because of the synergistic nature of data in the near future. Customers will seek information which incorporates SMAC data, and behind that will be the technologies of High Performance Computing, Big Data algorithms, as well as remote sensing data from space, and naturally additional telecommunications heft. New companies such as Orbital Insight and Dashboard are positioned to take advantage of data synergies, where satellite data is just one among many inputs to complex algorithm-driven solutions.

Orbital Insight aims to '… transform images from space into actionable insights', and their blog details end user solutions and applications (Orbital Insight website, May 2017). Closer to home, the Digital Dome project launched at the Iziko Planetarium in Cape Town in May 2017 aims to capitalise on the need for EO data integration with other platforms to provide insight. This insight is for both academic and commercial purposes, and requires massive graphic and computing capability to render data sets for a 3-dimensional projector to provide an immersive data-rich experience.

4.9 Technical debt

The central danger in having new industries join space is technical debt. Given the rapid cyclicity of the disruptive innovation model, technical debt can be found in many industries today, though the origins of the concept lie in software programming.

In the absence of a thorough technical grounding in a subject, newcomers may be capable of superficially entering a market with a new attractive product, but this new product is unsustainable in its environment. Given a thorough grounding in appropriate technologies, services and products developed by newcomers lack certain quality characteristics.

For example in software development, the underlying code, although it may fulfil its functional aspects, is substandard: unsupportable, unmaintainable, lacking in interoperability or easy upgradability and so on. In short, quality attributes which a seasoned architect or developer would pay attention to are not necessarily paramount to a disrupter whose chief aim is to bring a new product to market as quickly as possible: '… aspects concerning end-of-lifecycle aspects, system durability, information security and sustainability are often considered as an afterthought or a low-priority requirement that can be sacrificed in the heat of the race towards deadlines' (Christoph 2014).

Analogous to money, if technical debt is not 'repaid' it can accumulate and accrue 'interest', making it harder to repair or change later, and unaddressed technical debt causes software entropy. This is a situation analogous to entropy in closed systems following the second law of thermodynamics. As a system is modified, its disorder, or entropy, increases. This is why software patches can only maintain a system for a limited period, and at some point the entire system must be replaced, in a normal upgrade cycle.

The satellite industry creates and relies increasingly on software, making this concept highly pertinent to space. To make matters more critical to the space industry, the long term sustainability attributes such as security, resilience and low failure rates are not only important but critical to the success of a mission. Therefore there is a tension in software for satellite missions between accumulating technical debt and obeying traditional engineering requirements for space systems.

One response to this is to create re-usable Open Source systems. Open Source systems benefit from a greater number of developers and implementations, ironing out technical flaws with greater rapidity and therefore reducing risk. The government

sector has been and continues to be privacy and security oriented with respect to any technology relating to space. However, not all software connected to satellite missions resides in space, nor are all missions critical for national security.

The Hummingbird monitoring and control framework for small satellites is a case in point. This is a system designed to monitor and control a ground station, but could equally be used to monitor and control a satellite at the same time. Modern control frameworks (such as TANGO) allow the decoupling of functions from the structure of code, unlike older functionally designed systems. This frees implementation to be more about configuration, lighter weight, and highly adaptable.

The authors of the Hummingbird system point out that the risk-averse nature of the space domain has, unwittingly, increased technical debt. Because the space industry is reluctant to overhaul its software systems, they are now left with systems which have 'a large number of known bugs, requires esoteric knowledge to configure and stabilise, is overly complex and offers little in the way of modern interfaces' (Doyle, M. and Klug 2012). The Hummingbird Open Source system shares much in common with modern software systems: it is modular, written using a Service-Oriented Architecture approach, and this makes it effortless to swap protocols and modules. By 'interfaces' the authors are not referring to user interfaces but code interfaces, where a technical stack can be created to fulfil mission aims which includes a great deal of re-usable and public domain code.

The space industry, they say, is 'entering a new age, driven by low-cost hardware and software solutions. These modern solutions are driven by practical considerations, focusing on integrating and adapting 'off-the-shelf' products in place of specialised solutions' (Doyle, M. and Klug 2012). Since the requirement for longevity in space has fallen away for very small satellite projects, the question as to whether this new era of low-cost technology may be building up technical debt is moot. Certain sectors of the NewSpace domain may not care about longevity, and will sacrifice resilience for efficiency and short-term cost effectiveness. In any case, modern software systems are more robust than their forebears, and attempting to force compatibility with old systems by relying on clunky APIs and patches may entail greater risk.

Whether technical debt is a setback in the realms of disruptive innovation in the space industry remains unclear, and is a question outside of the scope of this study. It is a subject taken seriously in software development in the IT industry, but does not dominate software engineering in the space industry. In the space industry, software development (called 'software engineering', and usually following ECSS standards), concerns largely control and embedded systems and is not the same undertaking as software application development for a public marketplace.

4.10 What has Disruptive Innovation got to do with the user?

One of the characteristics of disruptive technologies that engenders their success is that they give people what they want better (cheaper, faster) than the current offerings in a particular domain. They 'challenge industry incumbents by offering simpler, good-enough alternatives to an underserved group of customers' (Baumann et al. 2006). If the disruptor's offering is better suited to market needs, this raises the question as to whether they are more responsive to users themselves, and why. Is it the case that disruptors pay more attention to end users or is the technology push model as prevalent amongst disruptors as the established organisations? What makes the disruptors special, apart from their lack of investment in a particular set of process, practices and products?

SPIRE is a relatively small new company in the space industry. Since it was established in 2012 through crowd funding it has successfully deployed 12 EO CubeSats into Low Earth orbit. However, it is, by its own description, not a satellite services provider, but a 'data driven organization' (Spire website, 2017) which is structured according to vertical data markets. Using data from nanosatellites it aims to 'improve human and machine behaviour'. The focus of this organisation is users and end user applications. Images of satellites themselves are not the mainstay of their branding, but rather what they can do with those images for specific markets. What these organisations have in common is data-centricity rather than space technology being central to their aims.

4.11 What has Disruptive Innovation got to do with Africa?

Disruptive technologies are relevant to a discussion about the orientation of space technologies for Africa in several ways.

1) Developing countries can present novel markets.
2) Barriers to entry with NewSpace technologies have relaxed and therefore allow organisations with less capitalisation to participate.
3) The lack of an established industry means there is nothing to lose by being more technologically innovative, in terms of existing business processes and investment in modus operandi, development platforms, personal contact networks, contractual obligations with suppliers, and so on.
4) There are no legacy systems to hold back the adoption of new technology.
5) There is an increasing workforce of educated young people, empowered by recent advances in e-learning and improvements in tertiary education in Africa, and greater mobility of this workforce in general.

Due chiefly to lower barriers to entry, as well as shifts in geopolitics, developing countries have and continue to invest in EO capabilities. Brazil, India, China and South Korea are already active. South African companies are developing remote sensing satellites and South Africa has already initiated a modest space programme. Kenya and Nigeria have purchased satellites in recent years. Algeria, Egypt and Libya are also developing their national space capabilities.

It is not so much the ability of African countries to join the space arena that is germane to a discussion on disruption, but that disruptive technologies are benefitting Africa in surprising ways. Some of these ways are explored in Chapter 5.

4.12 Disruptive technologies and the space industry

To sum up, the traditional space industry is being thoroughly disrupted, and not only in the remote sensing domain, which has been the main focus of this study. Rocketry, ground stations and launches are all being challenged by new styles of capability that perform similar functions, and there are new entrants from different industries

challenging established players. The space industry is far removed from its end users, with a more complex and fractured value chain than most other industries. Disruptors have a different set of drivers and are able to address user, or at least market, needs more directly than established industry actors. Part of that ability is due to a different perspective on scope and business value propositions, and part is due to them being less risk-averse and therefore able to exploit cheaper technologies.

What this discussion on disruptive technologies demonstrates is that it can affect the relationship between the space industry and markets. It can bring new business models to the fore, and allow new entrants, thus increasing competitiveness and lowering costs. However there is still a strong technology push. The sustainability of most of these new entrants is still questionable, but the size of markets they have opened heralds the potential for new and enduring business models and applications.

5 Implications of the space industry's limited user concept for social and economic development in Africa

5.1 Introduction

In December 1965 Unesco convened a meeting of experts in the development of space communication. The ensuing report paints a dichotomous picture. The world was on the brink of using satellites for mass communications and entertainment on an unprecedented scale, and the experts foresaw an either/or future:

> 'Satellite communication can reveal to us in a larger measure than ever before the greatest creative achievements of man, the greatest utterances in the field of poetry, drama and music. It can also in equally abundant measure flood our eyes and ears with the most unseemly trash for hours on end.'

These prophetic words carried with them a warning that:

> 'Since space communication needs the whole world for its arena, confining its benefits to those nations only which can afford them at present is likely to widen still further the gulf between the advanced and advancing nations leading possibly to greater strife, discord and eventual chaos' (UNESCO 1968).

Since these experts met in 1965 the economic gulf may have widened between the haves and have-nots, but socially and economically, and in many other ways, the world has become more connected, as well as wealthier *on average*. The participants at this conference could not have imagined the impact of mobile telephony and the Internet on social development, yet at the same time that they would have to wait almost 50 years before mass, affordable communications in developing countries truly arrived. Whilst there remains a wealth and technology gap between rich and poor nations, the poor nations are not the same as those who were lagging behind in 1965 (although African countries continue to be the most poverty-stricken and unequal in wealth distribution). The differences within countries are greater than the differences among them (UNESCO and ISSC 2016).

This study focuses on the gap between end users and those designing satellites, which has brought about a limitation in the use and take up of space-derived data. Commercial satellites are launched to provide services largely for those who can pay for them, and therefore satellites actively providing services for Africa are relatively few, as are applications developed to suit the needs of the region. The 'digital divide' persists despite the availability of mass telecommunications globally. The gap between satellite programme designers and end users is, as we shall explore, greater in developing countries than in the rest of the world.

In 1968, the report by Unesco: 'Communication in the Space Age' stated that consideration must be given to:

> '… The kind of association required between the developed and developing countries in the technological progress of the satellite, including scientific and engineering research on it, its development, construction, launching and final utilization. Clearly, the developed nations would be called on to make considerable sacrifices for the good of the rest of mankind who need a strong and effective helping hand, for the developed countries almost exclusively own or control the resources for developments in space, while those who will benefit to by far the greatest degree are the developing countries' (UNESCO 1968).

This still obtains 50 years later: satellite development, ground segment and launch capability are almost entirely in the control of developed nations, as are the applications that utilise the ensuing data. Technology migrates towards, or is imposed upon, contexts for which it was not originally developed. Questions about alternative contexts are not raised during the design, development and deployment phases of the vast majority of technology applications, throughout the value chain. Some applications have been developed specifically for Africa, and in these cases the end user is more likely to be a beneficiary than a commercial user, and these are considered below.

5.2 What are the differences between Africa versus the rest of the world?

To address the central question of this chapter, we need to identify the differences between Africa and the rest of the world in terms that are germane to space technologies and applications. We need to understand the geographic, political, economic and social factors that would give rise to differences in how space data may be taken up between African countries and the rest of the world.

The principal difference is economic: African countries are poorer, collectively, than other regions. Most of the Least Developed Countries (LDCs) are in Africa (UNCTAD 2016). Space technology is expensive, and using the applications derived from space technologies requires a piece of technology at least as sophisticated as a cell phone or computer, preferably connected to the Internet, and these remain economically out of reach for many of the world's poorest (United Nations 2009).

Economics isn't the only factor: digital literacy is much discussed in the topic of the 'digital divide' which has been the focus of a great deal of research since the phenomenon was identified and the term coined in the 1990s. Culture, working practices and local perceived need for digital services also play a part in maintaining digital separation between developed and developing countries.

The digital divide is important to address because, as Fuchs and Horak point out:

> 'The issue of global inequality is connected to the topic of the digital divide because technology is one aspect of material wealth and wealth production is more and more based on technology and knowledge. Africa is of particular importance here because it is the most marginalized and excluded region of the world'(Fuchs & Horak 2008).

African nations themselves perceive this significance:

> 'In times past, we searched for gold, precious stones, minerals, and ore. Today, it is knowledge that makes us rich and access to information is all-

> powerful in enabling individual and collective success. (Lesotho Ministry of Communications, Science and Technology, 2005).

As was identified by researchers decades ago, to be excluded from the digital domain is to be disenfranchised from a major part of modern economic life. In 2003, van Dijk, a well-known commentator on the digital divide, called this a *usage gap* rather than a knowledge gap, where participation in digital life is predicated on differential practical use and position in society, rather than knowledge alone (van Dijk & Hacker 2003). This is borne out by more recent research in sub-Saharan Africa discussed below, where class identification and social networks foster a culture of overt knowledge acquisition (academic qualifications) without a concomitant (and often assumed) contribution to a country's economy.

Fuchs & Horak (2008) go further to speak of 'digital apartheid' which 'means that certain groups and regions of the world are systematically excluded from cyberspace and the benefits that it can create'. Van Dijk (2006) speaks of a tripartite Marxian class structure, which is interesting to think about when considering technologies that may be appropriate for development. These classes are:

> 1. The Information Elite consists of people with high levels of education and income, the best jobs and societal positions, and a nearly 100% access to ICTs.
> 2. The Participating Majority which contains a large part of the middle class and the working class who do have access to computers and the Internet, but also possess fewer digital skills than the elite, information and strategic skills in particular, and use fewer and less diverse ICT applications.
> 3. The Disconnected and Excluded who are largely excluded from participation in several fields of society and have no access to computers and the Internet. (Van Dijk, 2006, quoted in Fuchs & Horak 2008).

This schema is particularly applicable given the gross inequalities that exist within African countries, and which typically follow rural-urban lines. ICTs for development address the third class of citizen: the 'Disconnected and Excluded', whereas the 'Information Elite' exist in a technological environment similar to those in many cities in the 'global north'. (The terms 'global north' and 'global south' are common

in economic development and used as shorthand expressions for developed and developing respectively; the term 'Western' having become a politically contentious expression).

Although economic education organisations such as Gapminder remind us that, in general, economic indicators for all nations continue to improve, the gap between rich and poor widens both within each country and between countries (www.gapminder.org). The average Gini index for sub-saharan Africa is one of the world's highest, and high inequality is 'divisive and socially corrosive' as remarked by Wilkinson and Picket, (2010), quoted in the UNESCO World Social Science Report, 2016 (UNESCO and ISSC 2016). This report shows that South Africa has been at the top of the charts for wealth inequality since 1994, when income and wealth indices began to worsen. Countries in Africa with the highest wealth Gini index are the mining or oil-producing countries: Botswana, Namibia, Nigeria, South Africa. Within-country indicators vary widely by gender and location (rural/urban) and this has ramifications for the take-up of technology-based applications. Therefore any sensible comparison of African countries with those in the rest of the world must bear in mind that the differences within countries are greater than the differences between them *and that this is more pronounced in Africa than in other continents.*

Figure 5.1 shows the penetration of Internet access comparing Africa to the rest of the world. Whilst Internet usage in Africa grew by 7.9% from 2000 - 2017, penetration as a percentage of population is 28.3%. The average world Internet penetration is 49.7%, with Europe and North America standing at 77.4% and 88.1%, respectively. The vast majority of African Internet access growth follows the rapid urbanisation of Africa in the previous decade (internetworldstats.com).

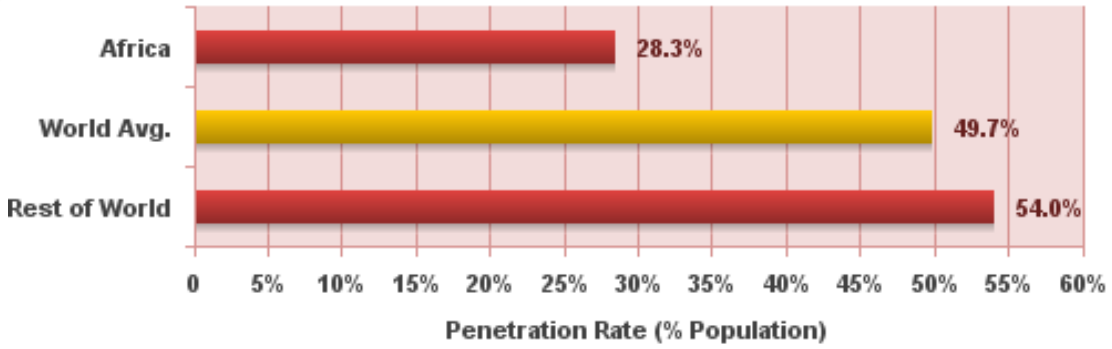

Figure 5.1: *Internet Penetration in Africa (internetworldstats.com).*

The model of a PC connected to the Internet prevalent in the 'global north' was too costly to be sustainable or scalable (Heeks 2008). Mobile platforms are used to access the Internet in the LDCs.

As far back as 8 years ago, mobile telephony reached more than half of Africa's population. Data from 2016 shows that just over 25% of people in Africa use the Internet, with mobile broadband subscriptions at 29.3 per 100 inhabitants (ITU 2016). From 2010-2015 Africa showed by far the highest growth rate in mobile subscriptions in the world at almost 12% per annum as it caught up quickly to the rest of the world. Africa's mobile subscription at the end of 2015 was 46% of the population of 1.13 billion. Mobile broadband take-up continues to accelerate and a quarter of all connections are to smartphones (226 million in 2015). This is set to rise to 2/3 of all subscriptions by 2020. The mobile phone industry has contributed 6.7% of Africa's GDP and 3.8 million jobs in 2015. The global average of mobile subscriptions is 63%, and to compare to the rest of the developing world, Africa is lagging behind, with the Middle East at 58%, Asia Pacific 62%, and Latin America 65% (GSMA 2016).

Significant barriers to the take-up of mobile services remain. African countries have among the highest total cost of mobile ownership as a proportion of income in the world. As of first quarter 2016, 3G and 4G networks covered 50% and 16% of the population across the region respectively; around 30% lower than the global average. (GSMA 2016).

Research has shown that the biggest obstacle to ICT access is cost, and in poor countries that cost is far higher than in richer countries. The lowest-earning 75% of

mobile phone users Africa spend high proportions of their household income on communications, with Kenyans spending as much as 27% (Elder, 2013).

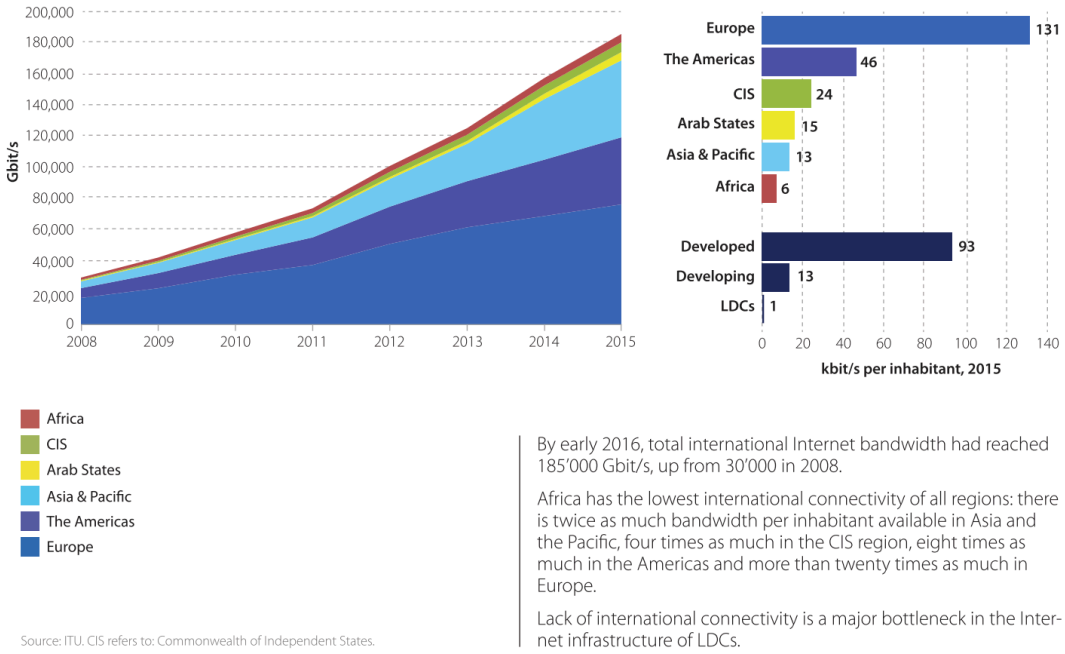

Figure 5.2: *Distribution of Internet bandwidth (ITU Development Bureau Facts and Figures 2016).*

Figure 5.2 shows bandwidth distribution in the world, with Africa by far the lowest in terms of access to higher bandwidth. There are many reasons for lack of investment in Internet bandwidth, despite this being heralded by some as a marker or causal agent in economic growth. These are absolute poverty rates, with impoverished governments having more pressing calls on the public purse, political instability, insurgencies, poverty, unreliable power generation systems, few planning controls, prohibitive taxes, geographical obstacles, sparse populations, and difficult legal access to rights of way. These factors inhibit the growth of investment in telecommunications but commercial drivers have overcome these setbacks as witnessed by the rapid growth in mobile services in the last decade.

5.3 Space technologies in Africa

Telecommunications and remote sensing are two major activities involving space in Africa. National security, which is a major driver for space technology in the rest of the world, is not prevalent, or data is not publicly available on this subject in the African continent. There are other space-driven activities and national space programmes run by African countries and some of these involve remote sensing and applications affecting the end user.

To try and make meaningful generalisations about the entire continent of Africa can lead to misleading conclusions, particularly given the fact that inequalities are greater within regions and countries than between. It is possible nevertheless to compare initiatives in space and space agencies. A cursory examination of the space activities of African countries reveals that few African countries have space agencies, and those that exist are not well resourced compared to the rest of the world.

Pan-African space initiatives such as the African Resource Management constellation (ARM) have taken many years and many talks, with few concrete outputs. The project involves Algeria, Kenya, Nigeria and South Africa, and includes a satellite designed in South Africa that may be launched in 2020, with an agreed budget of R500M ($38.4M). It is a constellation of micro-satellites owned and operated by different governments supporting a data source for environmental management information in Africa addressing African priorities (Mostert 2007). It sets out to address 'the need for regular high-resolution data over Africa for resource management applications.' This project had a thorough requirements derivation process involving users from African countries, with a view to providing applications across a range of subjects: agriculture, environment, disaster monitoring, land use, food security, water resources, fishing, mineral oil and gas exploration and peace keeping. Although this long list of applications may seem over-ambitious, they were crystallised into spatial, spectral and temporal resolution requirements using a thorough process. The fact that there is very little to show for the years of discussion attests to both the lack of resources in the clutch of developing countries in the project, but also to the fact that these are separate countries. They are not federated states, provinces, or districts with

common heritage. Many African countries are recently formed, riven with internal strife and border contests, and poor.

Two other African satellite initiatives are COPINE and RASCOM. Planned at the turn of the century, the United Nations project COPINE was to be a satellite-based information system that would link scientists, educators and professionals in Africa. There is little information about COPINE, and it did not come to fruition. RASCOM, the Regional African Satellite Communication Organization, was established in 1993 to provide telecommunication services, direct TV broadcast services and Internet access to rural areas of Africa. A private company registered in Mauritius was to implement RASCOM's first communications satellite. The underlying aim was to lower the continent's dependency on international satellite networks by pooling resources. France's Thales Alenia built the first satellite in France, RASCOM-QAF1, which was delivered in orbit in 2007 but crippled by a helium leak, and a second replacement satellite, RASCOM-QAF1R, was launched in 2010. Almost 18 years after the project initiated, there is one satellite built and launched by the French.

There are some success stories regarding African space endeavours albeit on a relatively small scale. In May 2017 the n-Sight1 nanosatellite was successfully launched into low Earth orbit from the International Space Station. This was designed and built in South Africa and forms part of the European Commission's QB50 project. These space activities are few and unfortunately (for sustainability and continuity) far between in the continent.

Table 5.1 shows the annual budgets of space agencies as available in the public domain. This is not adjusted for type of activity, but gives an idea of African space agencies' budgets compared to rest of the world. It highlights the difference in allocation of public funding for space activities between Africa as a region and the rest of the world (African countries are shaded in grey).

Country/ region	Agency	Budget (USDM)	Year
United States	National Aeronautics and Space Administration	19,500	2017
Europe	European Space Agency	6,271	2017
Russia	Russian Federal Space Agency	3,272	2015
Japan	Japan Aerospace Exploration Agency	2,030	2013
Germany	German Aerospace Center	2,389	2014
France	French Space Agency	2,170	2014
Italy	Italian Space Agency	1,800	2014
India	Indian Space Research Organisation	1,400	2017-18
China	China National Space Administration	1,300 500 (official)	
Canada	Canadian Space Agency	488.7	
United Kingdom	UK Space Agency	414	
South Korea	Korea Aerospace Research Institute	366	2007
Ukraine	State Space Agency of Ukraine	250	
Argentina	Comisión Nacional de Actividades Espaciales	180	2016
Iran	Iranian Space Agency and Iranian Space Research Center	72 + 67 = 139	2014-15
Spain	Instituto Nacional de Técnica Aeroespacial	135[l]	2009
Netherlands	Netherlands Space Office	110	
Sweden	Swedish National Space Board	100	2011
Brazil	Brazilian Space Agency	100	2015
Pakistan	Space and Upper Atmosphere Research Commission	75.1	2010-11
Switzerland	Swiss Space Office	10	
Mexico	Mexican Space Agency	8.34	
Libya	Libyan Space Agency	No reliable data	
Nigeria	National Space Research and Development Agency	20 approx allocated	2015-16
Kenya	Kenya Space Agency	No reliable data	
Egypt	National Authority for Remote Sending and Space Sciences	8.4	2016
Algeria	Algerian Space Agency	360	2002
South Africa	South African National Space Agency	11.8	2014-15

Table 5.1: *Space Agency Budgets (Wikipedia).*

This is not only involvement in the development of technologies themselves (launch facilities, satellite development, ground segment and so on) but also in the development of policy, regulatory frameworks and the more peripheral but important activities of public education and graduate training programmes. This means that African countries are the recipients but not the generators of space technologies.

These space technologies include various relatively new High-Altitude Platforms, UAVs and so on, as well as derived applications and services such as cellular communications, broadband Internet, and concomitant functions necessary for modern society: global positioning, weather forecasting, accurate time keeping, disaster mitigation, and so on. The long list of applications that use space data are therefore owned, designed, produced, maintained and supplied by agencies outside of Africa, and therefore not necessarily primarily for the benefit of those in the region.

Control over remote sensing services is a critical matter of sovereignty and regional security. As said by the CEO of the South African National Space Agency, Val Munsami in 2017: ‘ …reliance on foreign satellites means that South African satellite data users, which include about 40 national and provincial government departments, have no control over what images they are sent, what the images focus on and when they will get them.’ (Business Day, 03 February 2017).

5.3.1 Technopolitics

One of the challenges in space technologies for Africa is the political dimension, where ‘technopolitics’ comes into play, and this does not necessarily bode well for end user applications. Focusing on the case of two ambitious government-led ICT projects in Ethiopia, Woredanet and Schoolnet, Gagliardone (2014) identified the involvement of political forces in these technical projects. What he found was that:

> ‘Rather than employing ICTs according to donors’ demands of openness and democratization, the Ethiopian government has appropriated them to support its ambitious state- and nation-building process, while marginalizing alternative ICT uses promoted by other components of society, such as the private sector and Ethiopians in the diaspora’ (Gagliardone 2014).

The term "technopolitics" accounts for technologies being used for political ends, and this is rife in all countries, not only the resource poor. Many space technologies are used for political ends, and one could say that the very instigation for space technology from Sputnik onwards has been for spying and political competition, such as occurred during the 1960's space race. The difference with technopolitics is that there is the notion of a misappropriation, or obfuscation of the real aims of a mission, and this has ramifications for ICTs for development discussed below.

5.4 Space applications in Africa

If applications using space-derived data were developed specifically for the African continent, what functions would they perform and how would they differ from any other applications anywhere else in the world? What are the consequences of the fact that the vast majority of space-derived applications are developed outside of Africa according to paradigms derived from and suited for different contexts?

Applications using space-derived data in Africa lie chiefly in the domain of remote sensing, and the vast majority of these are specific EO studies. These studies for and about Africa are carried out by scientists both within and outside of the region, using tools such as Geographical Information Systems (GIS), and typically they examine a specific geographical area for a particular purpose. They are mainly commissioned by developed countries (scientific institutes, governments, aid agencies and NGOs), using either public domain data or specifically commissioned and targeted imagery.

The annual African Association of Remote Sensing and the Environment (AARSE) conferences attest to the bias on vertical scientific applications, and although worthy and necessary, these do not address the majority of the UN Sustainable Development Goals nor do they directly affect or address the needs of the general population. However useful these scientific applications may be according to their individual and specific purposes, they are piecemeal, confined to the science arena, and do not constitute widespread services delivered to governments or to the populace.

Listed below are typical developing country EO applications, and the numbers of papers in these areas were delivered at the AARSE conference which took place in Uganda in 2016:

Paper Topic	**Number of papers**
Agritech / Food Security	41
Human Capital Development	7
Conflict Management	7
Climate change	26
Disaster Risk Management and Resilience (Floods / Desertification and Fires / Landslides	28
Forestry	13
Water Management	30
Health	7
Urban development and management	21
Administration and Policy	3
Ecology and Environmental Conservation	33

The papers delivered described examples of EO data applied to particular use cases, and these were singular instances of scientific works applied to specific geographical areas.

In the 'global north' the entire value chain from space imagery to beneficiary is unbroken with many integrated services provided by governments and large commercial entities. Beneficiaries are digitally literate and have the technical means to take advantage of remote sensing data.

To take two examples, remote sensing applied to agriculture is commonplace for large farms in the US where agritech has been established for over a decade. It would be unthinkable for a large metropolitan planning agency in a major city in the global north not to use space imagery in transport planning. In developing countries, the use

of space imagery is in its infancy and is still applied without sustained integration into ongoing policy and processes.

Disaster Management is a complex field, and utilises heterogeneous data from a wide variety of sources, including, crucially, those from space. There are constellations of satellites constantly monitoring the Earth for signs of imminent natural extreme phenomena such as tornados and tsunamis, as well as the usual weather monitoring satellites. These constellations, such as the Disaster Monitoring Constellation for International Imaging (DMCii), monitor forests for deforestation, analyse climate and high-risk areas for food security, fires (though there are as well satellites primed only to seek out fires), and provide imagery to assist disaster relief efforts. As one would expect, these projects are internationally funded. Natural disasters do not obey national boundaries, and a considerable degree of expertise and resources are required to combine international data sources and organise responses. The EO component of disaster management is managed by international organisations, and African countries are reliant on data from satellites outside of their control to monitor and manage disasters. Although space assets are extremely useful both in determining the nature of the disaster and its impact, and also in providing communications where local infrastructure may be damaged, there are many logistical and organisational issues on the ground which hamper relief efforts (Dinas et al. 2015). The domain of disaster management provides a response to the hubris often found where novel technologies are deployed.

That images of Africa from space are not as widely used as images taken over other regions, or that images are not routinely taken by satellites passing over Africa (processed, stored, transmitted etc.), is not only because they are prohibitively expensive. The organisations and business processes that would utilise them are not in place in Africa. The demand is not provided by a populace or their governments, which are either digitally illiterate for the most part, or unaware of the benefits which can accrue from space imagery. African governments chiefly lack the continuity of expertise and intra-governmental processes and organisations to feed into services that can use space imagery. In the near future at least the cost barrier may be addressed.

5.5 Disruptive space technologies and Africa

The prime characteristic of disruptive innovation is that it offers either novel services, or much cheaper or more accessible services. Swarms of cheaper satellites are being launched by the disruptors, mentioned in the previous chapter, with global coverage. The price for satellite data is falling, and images become more widely available to Africa. The population of Africa is becoming wealthier, and is, more than ever, located in cities that are easier to service in terms of remote sensing and telecommunications. Here are two disruptive initiatives that will address availability and price. There are of course other attributes of space imagery required for scientific or vertical applications, where specific frequency, time and image resolutions are needed. However these initiatives may bridge gaps in Internet access and basic EO data provision.

OneWeb's goal is: 'To fully bridge the Digital Divide by 2027, making Internet access available and affordable for everyone' (Oneweb.world). OneWeb is building and launching 648 satellites communicating with small low-cost user terminals that can be located anywhere in the world. These can extend the reach of existing telecommunications networks as well as provide capability to create a local mobile network (e.g. for emergency situations).

Closer to the people and linking in with Coca-Cola's Internet of Things strategy, Coca-Cola South Africa, local bottling partner Coca-Cola Fortune, and BT (British Telecom) joined forces in 2014 to initiate a project to provide Internet access points at drinks dispensers. The aim is to provide those who have little Internet connectivity with 30 minutes of free-of-charge, uncapped access per device each day via their Wi-Fi-enabled drinks coolers. The vending machines are turned into hotspots by adding large routers that link to satellites via VSAT antennae. The results of their pilot, which involves two sites in South Africa, are not yet available.

Planet and SpaceX mentioned in Chapter 4 both have initiatives that will result in EO data being made available more cheaply, or free, for Africa. The implication is that

there should be an increase in the use of EO imagery in Africa for various purposes as imagery becomes cheaper and more plentiful.

In Malawi, a project using drones is underway after a successful pilot. UNICEF and the Malawian government have launched a project that will use unmanned drones to carry out humanitarian efforts in the country and, eventually, the whole continent. The drones will carry out three tasks: imagery, telecommunications to extend Wi-Fi and cellular signals, and delivery of small packets.

Whether these innovations prove *catalytic* for social change, as the mobile phone has done in Africa, remains to be seen. (Baumann et al. 2006) identified a particular type of disruptive innovation he named 'catalytic' as they are 'distinguished by their primary focus on social change, often on a national scale'. Remote sensing aids allow certain types of decision to be made particularly by large corporations and governments. These could bring about better provision of services with improved knowledge of populations and terrain, better change detection and so on. The wide availability of remote sensing data in Africa can also promote democracy by making it difficult for governments to hide humanitarian or environmental abuses.

5.6 ICTs for development

As early as the 1950s, Information Communication Technologies for social development has been a topic of enquiry with concomitant journals and conferences to stimulate action. ICT4D, as it is known, began as a response to the digital divide, in recognition of the importance of joining the knowledge economy for developing countries.

Health, education and governance are the main themes for ICT4D applications, as these entail social benefit. The main themes of the 2016 AARSE conference would be recognised as worthy subjects by ICT4D. What ICT4D often misses is the contribution of commerce to economic development, and to the traditional public benefit areas of ICT4D. Banking and personal finance, insurance, entertainment, e-commerce (B2C), e-business (B2B) and social media are important components of the knowledge economy, and of the lives of the poor. Current ICT4D (version 2.0, as it is

known, from the late 2000s onwards) is about reframing the poor as active producers and innovators of digital artefacts.

There are many problems in transposing applications across social contexts. As Heeks observed in 2008:

> '… developers rapidly recognized that plugging a peasant farmer or slum-dweller into Google offered limited value. Much of the information they required would not emerge because it was not in digital format.'
>
> 'Pro-poor innovation occurs outside poor communities, but on their behalf … it runs into the danger of design versus reality gaps: a mismatch between the assumptions and requirements built into the design and the on-the-ground realities of poor' (Heeks 2008).

This chimes with the author's experience described in the Introduction with the Ugandan judiciary's computerisation project. Assumptions are made by developers within and from the developed world, who at best regard their beneficiaries as like themselves but with less cash to spend. As was pointed out in Chapter 2, Schlagert stated in 1953 that few engineers are trained in the fields of economics, psychology and marketing, and we would add, anthropology.

As a result of the imposition of technological projects upon developing countries which have been developed from and for a different social and economic context, many ICT4D projects have floundered and have proved unsustainable or their artefacts and assets not used for the purposes for which they were intended. This was found to be the case by Gomez (2014) who noticed that Public Access Computing venues 'appear to be used more for building and maintaining users' social networks, personal relations and entertainment, and less for education, health, e-government or e-commerce activities.'(Gomez 2014). That poor people spend money on entertainment and personal relations comes as a surprise to those who feel that they should spend their resources on betterment activities such as education and health, which is often the (rather sanctimonious) subtext of ICT4D.

It is therefore more likely that the reason why ICT4D projects have not changed the world much is that they are an academic pursuit. Their primary output is academic papers, not an improvement of the lives of the poor. There is a dearth of research into the non-academic impact of ICT4D research, ironically identified in an academic paper aimed at researchers, by Harris in *The Impact of Research on Development Policy: This Much We Know*, which states that 'there is little if any impact on practice and policymaking in ICT4D' (Harris 2015). Whilst he offers a list of practical solutions, he recognises the need for incentives for academics to perform tasks outside of their remit, and urges research institute administrators and academics to 'provide strong leadership in supporting cultural changes'. There is no notion in his work that academics may not actually be capable or suited to work outside of a university setting, often situated in the global north.

That ICT4D remains an academic pursuit makes it even less likely to reach engineers who create space technologies removed from end users and real impact. However there are initiatives concerning at least EO for Africa, that draw together African countries to share experiences and pool resources, mentioned below.

5.7 Institutional data and applications for Africa

The African Group on Earth Observation (AfriGEOSS) falls under the Group on Earth Observation (GEO) initiative, which is a worldwide network and initiative whose aim is to: 'connect the demand for sound and timely environmental information with the supply of data and information about the Earth that is collected through observing systems and made available by the GEO community.' (GEO website). As such it is committed to Open Science. A primary tool of GEO is GEOSS, the Global Earth Observation System of Systems, which is 'a set of coordinated, independent Earth observation, information and processing systems that interact and provide access to diverse information for a broad range of users in both public and private sectors.'

Governments and policy makers are the core stakeholders and *raison d'être* of GEOSS. Oddly they do not appear to be very interested in the end user. The latest AfriGEOSS symposium in Ghana in June 2017 mentions the user once in the list of

its objectives: ‘Engage with end users, understanding needs and mechanisms to deliver user driven (sic) Earth observations solutions’, though none of the symposium’s panels, sessions, or posters reflected this. The outcomes of this symposium, which did not necessarily reflect the content of the presentations, did mention the term ‘users’ in four instances amongst over seven pages of lists of actions. The term ‘community’ is mentioned liberally without qualification or specific details as to how users and the community would be addressed. It appears that there is no alignment between what the symposium aimed to address and the practical mechanisms or even research to do so.

GEOSS aims to enlarge the user community but they are not enlarging or elaborating upon the concept of the user. Astonishingly, the word ‘user’ does not appear once on the GEOSS mandate, vision, mission and value web page (https://www.earthobservations.org/vision.php). Searching their site for documents with the word ‘user’ returns no results either. However the recently published GEO Strategic Plan 2016-2025 has redressed the balance and, in its 55 pages does mention the user (including end user) 30 times (GEO 2015). Whether this entails any plan to understand their putative users is not known.

The Monitoring for Environment and Security forum in Africa (MESA) is an EU programme whose objective is to support African decision-makers and planners in designing and implementing policies and development plans in areas which can be addressed by EO data. The project takes place from 2013-2018 involving all African countries. The initiative includes various services including training, the provision of reports and tools and other enabling technologies to improve the use of EO data. Like other initiatives it is geared towards the scientific and technological and does not concern itself directly with users or beneficiaries.

What these and other programmes show is a strong bias towards individual scientific projects using EO data. Each one has its rationale and outcomes, but they are not geared towards users who are non-specialist. They are designed and operate well within a scientific paradigm. This is not to criticise such useful programmes and

initiatives, but to point out that they are not designed for, nor concerned with, the user.

5.8 Pre-requisites for more pervasive space technology in and for Africa

Carl Sagan famously said in Episode 9 of his 1980 TV series Cosmos: 'If you want to make an apple pie from scratch, you must first create the universe.' Economic and social development are holistic enterprises involving the interactions of many complex systems. If the end goal is pervasive space technologies in Africa, where remote sensing is utilised in the same manner in which it is in the global north, then a raft of inter-related infrastructures and features need to be put in place. If ICT4D is to become redundant, is it only access to broadband by the vast majority of people in Africa which will satisfy criteria to retire ICT4D?

What this raft of inter-related infrastructures and features consists of is not obvious. Even what could be considered basic pre-requisites such as a constant electricity supply are not actually needed, as can be seen in the example of Coca-Cola's drinks-and-Wi-Fi dispensers, where fuel-driven generators provide the power. Telecommunications infrastructure could also be thought of as necessary, but this has been 'leap-frogged' in Africa by mobile cellular technologies, allowing telephony to spread rapidly, with no impedance from pre-existing networks and relationships. Initiatives to provide Internet access by balloon or UAVs prove that widespread terrestrial or even satellite infrastructure is not technically required.

While limitations and barriers to physical pre-requisites may be addressed or circumvented, social and cultural barriers are harder to identify. Changing governance and business practices to incorporate new ways of obtaining and acting on information is not a straightforward undertaking and there are no common blueprints to apply across the African continent. As shown above, barriers to the further use of space technology in Africa are not merely economic but cover many governmental and organisational factors, as well as cultural norms which are further explored below.

Furthermore, even if the Internet were widely available, economic development does not necessarily follow. Access to the Internet may be necessary for inclusion in a knowledge economy, but the relationship between this and economic development (lower unemployment, higher GDP) is not proven. This is a highly contentious and much-examined area of ICT4D research.

In their study on engagement with the knowledge economy in sub-Saharan Africa, Ojanperä et al. 2017 reveal that:

> 'While connectivity is an important enabler of digital content creation, it seems to be only a necessary, not a sufficient condition; wealth, innovation capacity, and public spending on education are also important factors.'

They conclude from their research that: 'transformation into a knowledge economy requires far more concentrated effort than simply increasing Internet connectivity.'

Their study examined knowledge-intensive content creation, their three key metrics being spatial distributions of academic articles, collaborative software development, and Internet domain registrations. What they found was that in sub-Saharan Africa, compared to other geographic regions in the world, more academic articles were produced (traditional knowledge production) than 'digitally mediated knowledge production' (collaborative software development, and Internet domain registrations). The former do not translate directly, if at all, into economic growth. Academic institutions, while perhaps necessary for long-term economic development, are a cost that a country must bear, rather than a source of income. However this academic bias isn't hard to understand from the point of view of individuals in the LDCs.

The work of Jeffery (2010) concludes that the middle classes in postcolonial countries reproduce their power through cultural and social strategies, not through business: 'In the context of an underdeveloped formal economy, middle-class status often depends upon being able to marshal cultural capital and social connections successfully.' When considering space technologies for Africa, it is the middle classes who will engage with them, and whilst ICT4D typically focuses on the poorest sectors of society and public good, it is the middle classes, the digitally literate with education

and access to the Internet, who would typically utilise and be champions of space technologies in the science, policy and business sectors.

It is worth touching on who this middle class is in Africa. Are they homogenous? What are their aspirations, values and constraints? Can the same criteria be applied to the middle classes in each African country? Since the early 1990s there has been increased interest in the concept of a 'global middle class'; whether this exists, how they may be identified and whether there are similarities worldwide in their attitudes and behaviours.

Shimeles and Ncube (2015) point out that in Asia and Latin America, the middle classes played a driving role in economic development, but there had been very little interest or statistics about the middle classes in Africa. Using Demographic and Health Survey data for 37 countries covering the period 1990-2011, they show a modest rise in the size of the middle class in most African countries in the study. The probability of retaining middle-class status over the period was high at 75%, though the probability of becoming asset-poor was very high, at 84%. Their careful statistical analysis concluded that the continent continues to struggle with widespread poverty and deprivation and that a very important factor driving asset ownership is education (Shimeles & Ncube 2015). They also portray a complex picture where it is difficult to make generalisations and comparisons between the middle classes in Africa and elsewhere.

Loayza et al. (2012) found that a large middle class can play an important role in reforming institutions:

> 'When the size of the middle class increases (measured as the proportion of people with income above 10 US dollars a day in purchasing power parity (PPP) terms), social policy on health and education becomes more active and the quality of governance regarding democratic participation and official corruption improves.'

While there is a correlation between well-functioning institutions and the existence of a robust middle class, it is not clear whether this relationship is causal. It is not hard to see that good institutions and governance are necessary for using EO data. Therefore

it could be concluded that a strong middle class is necessary in a country to foster utilisation of space technology.

Note that the definition for inclusion in the middle class sector used by Loayza is merely $10 income per day, which, on top of other vital expenses, won't pay for a computer or Smartphone with broadband subscription. Perhaps it ought to be the upper classes that are investigated with respect to space technology.

5.9 Pre-requisites to support Earth Observation applications

At present there are many projects to introduce the benefits of space imagery to farmers in Africa. Improving agricultural yields, managing climate change and drought, and modernising agriculture in Africa are important subjects. The use of imagery from space is crucial in improving agriculture in Africa and in assessing food security According to the latest update from the agricultural monitoring project AfriGAM, presented to the 2017 Proceedings of the AfriGEOSS Symposium, food production needs to increase by 70% by 2050 (AfriGEOSS 2017 Final Proceedings). Projects using space imagery for improving food security for Africa and for monitoring effects of climate change are run by international funding programmes and universities, usually with a combination of local and overseas expertise and resources. A good example is provided by the paper *Assessing drought probability for agricultural areas in Africa with coarse resolution remote sensing imagery* (Rojas et al. 2011), which uses data from a variety of satellites including other food security projects such as the Famine Early Warning Systems Network, a USAID programme. This is typical of multilateral remote sensing projects: they are highly technical and scientific involving a great many scientists and technologists.

The use of space technology to improve crop yields presupposes a particular set of conditions if the end user is a farmer. The farmer must have a need for specific information about crop health, and must be able to interpret the data and act on it. The farmer must exist in an environment where to use external sources for information is accepted practice, and where information veracity can be judged. For this, a certain degree of institutional supporting measures must be in place: perhaps a Farmers' Union which can act as an interface to government, to specify and interpret

requirements for space imagery; training and information dissemination programmes must be present so the farmer hears about and understands new initiatives, and can assess the return on investment. The farmer also must have resources, be they financial or personnel, to spend on the technology needed to utilise space data. The farm must be a substantial size to warrant the investment. Lastly, the attitude of the farmer must be one that embraces new processes and approaches, in short, an educated and empowered individual who can harness information, perform their own analysis, conclusions, and have the confidence to act afresh. There must be a good relationship between the landowner and the person who works on the land. Farmers in Africa rarely own the land they work on.

A pre-requisite for EO for urban development in Africa is governmental institutions with capacity to use EO data. In South Africa for example, municipalities have begun to use images from a variety of high-altitude platforms, airborne vehicles and satellites to manage cities, though these activities are still in their infancy. New business processes, key performance indicators for officials, and general attitudes and other aspects of change management need to come into effect.

Health covers a plethora of different approaches to using space data, from SMS reminders to comply with medicine ingest, to determining geographical areas for disease control and drug supplies. Healthcare informatics for developing countries is a well-funded and researched topic, and like many others linked to ICT4D often does not concern itself directly with space technologies.

What is common to EO-based projects is a focus on the technology itself. Individual EO projects are well funded and resourced by external agencies, and are successful in achieving their specific objectives; but these are projects, not routine processes embedded into governance structures, policy and practice. Projects come with a date when funding dries up and when project activity ceases. For EO data to be incorporated into routine processes in Africa requires a list of actions, depending on the objectives, at the very least:

- Government infrastructures must be functional (e.g. research institutes, statistical bureaux).

- These agencies must have the capacity to utilise EO data
- Processes and policies must be in place and enforceable

EO projects with a view to sustainability tend to focus on technical training alone, whilst there are many other aspects to continued use of EO data. Government institutions continue to strengthen in Africa over time, but strong institutes are a necessary although not sufficient pre-requisite for the sustained usage of EO material. Social and cultural aspects, which are typically absent from space technology projects, play their part in determining whether and how EO can be successfully integrated into processes and working practices.

5.10 Technology and cultural norms

A technocentric view ignores the social and cultural components that may determine whether and how a technology is used in any given context. The same technology may be used in different ways in different countries or contexts, making international or intercultural generalisations and assumptions about technology acceptance and use difficult. There is a body of research on the intercultural organisational and social factors surrounding technology use, particularly in the field of ICT4D, but this remains largely within the originating academic disciplines. It is little wonder that engineers and the designers and procurers of space technology are unaware of these intricacies.

Even what appear to be the most straightforward space-derived benefits, such as the provision of weather forecasting, are riddled with complexity and social contention, as Amissah-Arthur (2003) found in rural Kenya. Over a decade ago, research into climate forecasts for rural farmers in Kenya identified a gap between available services and information that was ‘likely to be useful to farmers’. Amissah-Arthur’s approach to ameliorate this situation was to create a typology of users based on their geographical locations which, she felt, determined many other factors such as their production systems, market forces that determine credit, demand, and input availability. The outcome of her study was a methodology that would enable climate information to be better targeted. Her own conclusion was that her study was limited for several reasons, one of them because it didn’t target the ‘decision-makers’

(presumably the land owners and not the farmers themselves). '…the capability to integrate these forecasts with farmer's agricultural strategies and their decision making processes are still very weak'.

An example of more recent research which does involve the end user with greater sophistication, is Baptista and Oliveira's 2015 study on mobile banking, applying the extended Unified Theory of Acceptance and Use of Technology (UTAUT2) mentioned in Chapter 2 and shown in Figure 5.3. This research incorporates cultural values to examine how groups of people in Africa take up mobile banking. This study is significant because of the importance of mobile banking to regions where access to financial services remains problematic, such as for those living in rural areas. In many African countries a visit to the bank is a lengthy, costly and unpleasant affair involving difficult physical access in city centres, hours of queuing, and, in many countries, significant danger in travelling from a bank with cash.

Using the modified technology acceptance model, Baptista and Oliveira were able to analyse some of the factors influencing users' acceptance of mobile banking out of a collection of cultural moderators. A limitation of their research was that the cultural models adopted could not be used to generalise about a country since cultures vary widely within countries. This is a limitation for all cultural studies, and one of the difficulties of trying to incorporate social factors into technological design.

The most visible and successful mobile banking service in Africa is the Kenyan M-Pesa system, launched in 2007. This allows money transfer, financing and micro financing services using a mobile phone. In Africa, M-Pesa has now expanded to other East African countries. Examining what factors encourage or inhibit users to take up such services should at some point filter through to developers who can then tailor their offering, though Baptista and Oliveira offer no mechanism by which this may occur, exhorting only further academic research.

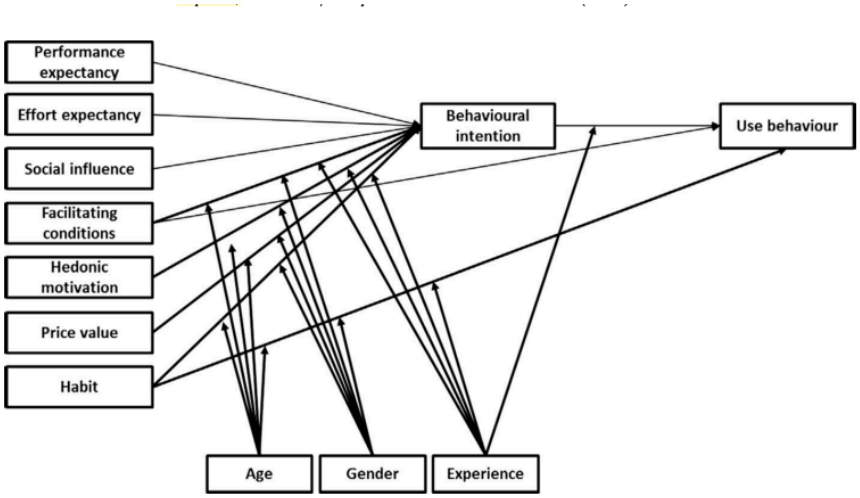

Figure 5.3: *Unified theory of acceptance and use of technology (UTAUT2) model (Baptista & Oliveira 2015).*

Anthropologists dig deeper than information specialists or technologists into cultural practices, with a greater philosophical and theoretical rigour. Two fields of enquiry have arisen since the 1970s. The field of Science and Technology Studies looks at the interstices between the history of technology and material culture, and the philosophy of science. Digital anthropology examines modern digital technologies through the lens of social anthropology.

Anthropology has long been interested in space as a social construct. Social geographers researching GIS systems within their research frameworks noted that 'boundary objects separate different social groups at the same time that they delineate important points of reference between them' (Harvey & Chrisman 1998). GIS systems and the technology that supports them are not socially and politically neutral. They are constructed within a particular social paradigm. The concept of boundary objects within social-constructivist theory gives us new ways of looking at the relationship between society and technology. The boundaries reinforced or created by GIS systems do not occur within a social and political vacuum: '…every instance of GIS technology is embedded in an intricate web of social relationships, and remains surrounded by multiple contentions (Curry, 1994; Sheppard, 1995 quoted in Harvey and Chrisman, 1998). GIS technologies are created within a complex web of negotiated relationships between a great many stakeholders, all with their agendas and desired outcomes for the GIS activity. What is included and excluded from a mapping

exercise, what is interpreted as standard, and what boundary objects are chosen as significant; each of these decisions occurs within a socially constructed setting.

The user within this setting may be the GIS specialist inputting the data or constructing the ontologies and structures that will guide the data input technician. It can also be the person who reads the ensuing reports and takes decisions based on them; the client who wrote the plan guiding the GIS project or the agency paying for it are all important stakeholders. At each turn, the decisions made in any GIS project are done so according to implicit rules, attitudes and values that are highly contingent and can be negotiated.

As can be seen in the example of the construction of a GIS tool and its data, the user, even the end user, is a category that can be decomposed. When Harvey and Chrisman turn their attention on a micro level to a specific remote sensing project observing wetlands in the US, they pinpoint scores of actors in the network, and attest to the social complexity of the endeavour: 'GIS technology and technoscience are not monolithic autonomous edifices but the localized results of processes of negotiation that involve the construction of artefacts to fit various social perspectives' (Harvey & Chrisman 1998).

More recently, DeNicola (2012) has explored the interdisciplinary field of what he calls *geomedia*, a confluence of social geography and media studies. DeNicola has conducted ethnographic work on the training of satellite image interpreters in India, concluding that: '…digital culture is posited as placeless and homogenizing, [but] when it comes to actual practice, digital culture remains thoroughly socialized and materially entangled with spatial experience' (DeNicola 2012). His work is published in *Digital Anthropology*, a collection of studies by anthropologists interrogating not only the impact of digital technologies on human life, but also how these technologies can be used to reflect on how humans define themselves.

5.11 The user concept in African space technology projects

As can be concluded by the discussions above, the user is part of an information system, and that information system is bound up with and dependent upon space

technologies. That information system is also part of a wider, fluid and amorphous social context. The end user or beneficiary of any space technology project lies many steps, organisations and processes away from the instigators of that project, and those instigators have little knowledge of the end users.

All actors within a system are part of a social environment, not only the end users. That social environment dictates all actions and designs. The engineer developers themselves are subject to constraints they are largely unaware of in their endeavours, as are the clients and organisations who specify the space missions. How this affects the purpose of this study will be further exhumed in Chapter 6.

In Africa, with its characteristics of poverty, poor administration and governance, and geographically dispersed populations, the gap between technology project and user is attenuated. In addition, the user is subject to technologies developed by and for different contexts, and contexts that do not take cultural differences into consideration.

Technological projects in Africa tend to be in the ICT4D domain, where the users are beneficiaries. These are well researched but not well integrated nor sustainable. The problems found routinely with technology adoption in the global north are amplified in the global south. This phenomenon is described by Toyama in the 'Law of Amplification: A Simple but Powerful Theory of Technology's Social Impact' (Toyama 2015). He points out that theories of social determinism (which underpin many anthropological frameworks) say that technology is created according to human intentions. At the same time, the degree of technological impact depends on existing human capacities. It follows therefore that 'technology's primary effect is to amplify human forces' (Toyama 2015).

In *The Road Ahead*, Bill Gates wrote:

> 'The first rule of any technology used in a business is that automation applied to an efficient operation will magnify the efficiency. The second is that automation applied to an inefficient operation will magnify the inefficiency' (Gates et al. 1995).

In extensive studies on educational technology throughout the world, Toyama found that introducing the Internet and computer technology can be a distraction and burden, and that there is no substitute for good teachers, well-resourced schools, and conscientious parents. The student end user, in order to benefit from technology, requires a raft of infrastructure: IT support, budget for upgrades and maintenance, highly trained teachers. In developing countries these are harder to put in place, and additionally the global south suffers from climatic and social conditions contributing to more expensive technology upkeep: dust, heat, vandalism and theft, and more costly telecommunications.

The same can be true of remote sensing projects, where space images are to be integrated into GIS-based projects. The communities who will use those images need them to have certain characteristics of spatial, frequency and time resolution. The end users of those projects, be they government policy makers, GIS programmers, or the beneficiary (farmer, local community, citizens), need continuous support. A one-off project with its self-contained budget, start and end dates, will not impact society in any substantial or sustainable way.

The users of Earth imagery are those involved in sophisticated projects and generally GIS tools are brought in to embed Earth images into an information system that can be interpreted by specialists. The beneficiaries of such systems are diverse and many are not aware that they exist: the general population benefitting from a forest not entirely burning down; insurance companies who need to correctly assess premiums for properties potentially subject to coastal erosion; citizens who need to be protected from food scarcity; road users who need to travel in a timely, orderly fashion. However rational or scientific GIS systems may appear to the engineer or scientist, they are, as we have shown, part of a complex social system complete with values and norms, which are opaque to both engineer and end user.

Two features emerge from this chapter. All actors, from technology creator to end user act from within a social system whose workings they are likely to be unaware of. Each actor has particular views on the system; only it is the technologists' views that

obtain. The end user in Africa is by and large a passive recipient of technology developed and imposed from elsewhere.

Secondly to use space data properly, whether it be telecommunications or remote sensing data, entails a list of pre-requisites which are for the most part social and political rather than technological. The consequences of these features will be explored in the final chapter.

5

6 Exploration

In examining the user concept and how this frames satellite missions, we have compared the space and IT industries in how they view and treat the user. Specifically the architectures of space and IT developments were dissected to get to the detail of how the user and user requirements are characterised and determined. Next, there was an exploration of so-called disruptive space technologies, where the IT industry has encroached into the territory of the space industry. Due in part to the business models and structure of the space industry, as shown in Chapter 2, the distance between the user and developers in the space industry continues to be very large. Lastly, in Chapter 5, we looked at the consequences of this gap for the African continent, and what this means in terms of the design, application and take up of space-derived technologies in cultural contexts very different to their origins.

Space technologies do not exist in a social and political vacuum. What then are the tools available to interrogate the social, political, and cultural environment of a space artefact or mission? Why should there be a vast gap between understanding of the users' contexts and the development of space missions whose end results are technologies to be used by citizens? Should there in fact be any cognisance of users from other cultures, or is it the case that everyone on Earth must adapt to the cultural framework of whatever technologies are presented? This includes adapting local regulatory and legal matters as well as business practices and norms. It is not as trivial a matter as American English being taken as the norm (as American spell-checkers become the arbiter of written English language), but is a thorough manifestation of technological colonialism.

This study has maintained that there are architectural reasons why the user is not adequately considered in the design of space missions and applications, and that the usual development processes preclude adequate treatment of the user. In addition, the structure of the space industry means that the *end user* is not consulted directly or thoroughly about mission goals. There are other reasons: risk aversion in the space industry, as well as the greater length of the value chain compared to other technical

domains. But beyond these reasons are deeper structures at play. This chapter explores these broad, related questions and points to some underlying causes.

6.1 Technocentrism

One of the shortfalls of most approaches to the analysis of technology is the assumed deterministic quality of research. The viewpoint for analysis is taken from the technology under study itself, and assumptions about the use of that technology are made on the basis of technology, analysing reactions to technology according to success factors and Key Performance Indicators that are technologically biased. Many other perspectives on technology exist, although the body of knowledge on this subject is not generally known, accessible, or available to those who create technologies.

As discussed below, technicians are not schooled in divorcing a technological artefact from the social, political and environmental context of its original design. That environmental context includes the business environment, regulatory frameworks, national policies and stakeholder types which obtain in any particular country, as well as norms and values implicit to a community of practice. An engineer or developer may not be aware that the technologies they develop are created within a particular social paradigm at all, and therefore be insensitive to alternative environments. Bearing in mind the case study presented in the Introduction concerning an information system conceived and designed elsewhere for implementation by the Ugandan judiciary, a lack of awareness of differences in social context are very real and have impact on the effectiveness or applicability of technology.

An engineer would read nothing amiss in the statement that there are markets in Africa for high-resolution space imagery. In fact, nobody needs high-resolution images. People need to better plan for emergency services to support informal settlements; farmers need to know when is the best time to plant and harvest; those in business need to connect with each other. To describe a market in terms of a technological artefact is technocentric. There is nothing wrong with this as a shorthand for those working in the field. Unfortunately this becomes technocentrism,

as this viewpoint becomes pervasive and unquestioned in the space industry, and the focus turns away from the end user to a particular feature of technology.

The space industry's chief concern is technology: the technology to get into space and stay there, and perform a useful function whilst in orbit. Most people working in the industry are naturally interested and educated in technology. Similarly in the IT industry, the terms 'geek', 'nerd', and 'propeller-head' are proudly borne. However, as shown above, the IT industry has had to turn its attention to the end user in order to survive in a highly competitive, high product-turnover environment. The space industry, mostly led by governments, has not had to be consumer-orientated, and the task of attending to end users has fallen to others.

An interesting question is whether these end users are worth consulting. Since technologists understand the limitations of their craft and end users do not, it could be said that technocentrism is justified. Consulting end users *is not thought to* result in useful material that can be applied to technology design. The IT industry's JAD sessions, workshops and brainstorming sessions involving end users may not be relevant to satellite developers, who can anticipate what image characteristics a particular application may need. In some satellite projects, the client is unsure about requirements, and the developer must assist the client in their determination, and this can involve indirect consultations with potential end users. These scenarios are described in informal discussions with satellite developers, but are not formalised.

Sometimes, technology developers deliberately release products without knowing what the end user wants. In fact, they sometimes create markets for their products where none existed or were dreamt of by users. As Bloomberg Business Week declared in their online article about tiny satellites ushering in a new space revolution: 'Planet Labs and other companies are sending hundreds of low-cost satellites into orbit. We're only beginning to understand how that will change life on Earth' (Bloomberg Business Week, June 29 2017). The new space start-ups 'envision an era in which rockets take off daily, filling the skies with satellites that sense Earth's every action—in effect building a computational shell around our planet'. Vertical markets (such as agritech or weather forecasting) may be mentioned by new space start-ups in

their marketing material, but in fact they are not clear about exactly who will use this 'computational shell' or why. It just seems like a good idea. To be fair, not all good business ideas are backed by lengthy academic discourse and theory, business models and thorough, rational consideration. Nevertheless, with hindsight it is sometimes possible to trace the history and philosophy of certain approaches and movements, to 'peer under the hood', which is what we attempt to do below.

6.2 Theoretical approaches to IS design and behaviour

As has been established in this study, the applications of certain space technologies, be they through remote sensing or telecommunications, form part of information systems. If an engineer or developer is tasked with designing a system for use in a cultural setting (and all settings are cultural) which is very different to one with which he or she is familiar, it is unlikely that they would be able to call upon complex sociological theories to assist in the design process, nor apply them to their work. As Walsham states:

> '…working with ICTs in and across different cultures should prove to be problematic, in that there will be different views of the relevance, applicability, and value of particular modes of working and use of ICTs which may produce conflict' (Walsham 2002).

Added to which, cultures are not static, and each location where a system will be deployed will consist of many different cultural modes and responses to that system. There is no one 'African' culture as could be implied by the title of this study, and not even a homogenous 'middle-class culture' as we found in the previous chapter. What is meant by cultural sensitivity, or to create a technological artefact responsive to culture, is an open-ended, undefined, non-linear and changing problem. These are not the sorts of problems for which engineers are trained to find solutions. The term 'culture' itself is fluid and open to interpretation, and hardly likely to be used as an item in any data dictionary, functional decomposition, or product breakdown structure. It is left deliberately undefined here, but could be thought of as a collection of shared values, symbols and behavioural norms pertaining to a defined group of people.

Over time, ideas from the social sciences can percolate through to become ‘general knowledge’ and form part of the zeitgeist of a society. For instance, some Freudian and Jungian concepts have found their way into common parlance, such as ‘the collective unconscious’ and ‘Freudian slip’. However there is no direct or formal route from social sciences research through to engineering. Over the last 15 years or so, some notions from social anthropology have found their way into the *academic* subject of Information Systems, but this constitutes a very tenuous link to space engineering practice, artefacts and applications.

At the turn of this century, the academic field of Information Systems began to take an interest in sociology and in particular social anthropology, to provide a framework for cultural analysis. A promising approach is provided by structuration theory, as discussed by Walsham (2002). Here, he proposes a practical tool based on structuration theory to assist in the understanding of a given social environment into which an IS may be introduced. The tool itself, which is a table designed to highlight features of a specific IS implementation, cannot be taken at face value, and a deep grasp of sociological theory is required to glean practical value from it. Outside of academia it is not pragmatic to believe that this analytical tool could be adopted by software developers or engineers in order to improve implementation or, for example, to understand or address user-resistance.

Sociological theories require a whole new field of discourse and framework of reference and values, of a type not to be found in an engineering curriculum. Structuration theory (Giddens 1986) is especially intractable, is not formulaic, and cannot be understood on its own without having grasped something of the history and lexicon of sociological thought. Furthermore, it is unlikely that new complex perspectives in Information Systems will be taken up by commercial entities unless they can be reduced to simplistic models, and the application of Table 6.1 is deceptively complicated. This particular tool is shown here as an example of the differences between the disciplines of engineering and sociology.

Structure	• Structure as memory traces in the human mind • Action draws on rules of behavior and ability to deploy resources and, in so doing, produces and reproduces structure • Three dimensions of action/structure: systems of meaning, forms of power relations, sets of norms • IS embody systems of meaning, provide resources, and encapsulate norms, and are thus deeply involved in the modalities linking action and structure
Culture	• Conceptualized as shared symbols, norms, and values in a social collectivity such as a country • Meaning systems, power relations, behavioral norms not merely in the mind of one person, but often display enough systemness to speak of them being shared • But need to recognize intra-cultural variety
Cross-cultural contradiction and conflict	• Conflict is actual struggle between actors and groups • Contradiction is potential basis for conflict arising from divisions of interest, e.g,, divergent forms of life • Conflicts may occur in cross-cultural working if differences affect actors negatively and they are able to act
Reflexivity and change	• Reproduction through processes of routinization • But human beings reflexively monitor actions and consequences, creating a basis for social change

Table 6.1: *Structuration Theory, Culture, and ICTs: Some Key Concepts* (Walsham 2002).

Structuration theory is presented by Walsham as particularly applicable to the study of cross-cultural working and IS: 'The crucial point here is that structure … is seen as rules of behavior and the ability to deploy resources, which exist in the human mind itself, rather than as outside constraints' (Walsham 2002). Human action and 'structure in the mind' are composed of the inextricably linked dimensions of systems of meaning, forms of power relations, and sets of norms, and it is these and their reproduction through behaviour which can be examined and made sense of through structuration theory. At the end of such an analysis, a deeper understanding of how

the information system is situated within a network of actors will emerge, enabling the technologist to better fit the system to its social context, or at least provide explanations for situations where the implementation fails. Table 6.1 is taken verbatim from Walsham and most non-sociologists would find the language requires a great deal of explanation, just as a satellite schematic would be incomprehensible to most sociologists.

It is worth pointing out that two paradigms characterise much of the research in the Information Systems discipline: behavioural science and design science (Hevner et al. 2004). What is described above with the application of structuration theory looks at the behaviour of an implemented IS. Operations Research also generally examines behaviour (of the human and non-human components of a system). Design frameworks were covered in the earlier chapters.

6.3 Sociology and psychology applied to IT and space

As mentioned in Chapter 2, 'Human Factors Research' in computing focussed on cognitive psychology and in particular those aspects readily reducible to statistics. Individual human characteristics were examined from the point of view of sensory and required motor skills to improve the human-computer interface (the author has a Masters degree in this subject from 1984). This research has improved such technologies as computer typefaces and anti-aliasing techniques, and certain aspects of the design and operations of peripheral devices, but it focuses on instances of human beings and not on collective behaviour, as anthropology does.

Aspects of Operations Research have made their way into Information Systems development that regard the digital system as part of a group of processes that include human workflows situated in the workplace. The theoretical underpinning of this work was weak and implicit, the works of Weber and Durkheim (founders of sociology) being long buried under a century of social science research. There are however many more commercially oriented frameworks routinely used in the analysis and design of information systems, most having arisen in the past 40 years. Commonest among these are the Zachmann framework, touched on earlier, and Porter's Value Chain model and their variants, extensively used in business. These

frameworks derive from Systems Thinking whose origins are from biology research in the early to mid-20th century, and before that, some say, Eastern philosophy (Pan et al. 2013). Systems Thinking informed systems engineering which is the basis for the systems methodologies behind space mission development.

The history of systems engineering and methodologies in the space industry may have their roots in more holistic, human-centred philosophies, but today the software developer and engineer will not normally be familiar with them, nor will they have the tools and norms in their industry to apply this knowledge. The problem may boil down to "modern" education systems which persist in dividing education into arts and sciences.

This division is one perpetuated by institutions such as the University of Cape Town whose very architecture espouses the vast perceptual gulf between *ars et scientia,* with the Humanities Faculty at one end of the campus, Sciences at the other, and Engineering and the Built Environment in-between. At one end of the campus are the students sporting ponytails with no make-up or embellishment beyond the purely practical. At the other end of the campus is the Faculty of Commerce, where students grasp that content is not all, and spend their university years networking and improving their social standing, entailing a great deal of grooming and fashion-consciousness.

There have been attempts in recent years to bring non-engineering subjects to the engineer, and arts subjects to medical students, as electives (Bailey, 2015). At the University of Cape Town, South Africa, engineering students must complete one approved liberal arts elective:

> It is a requirement of the Engineering Council of South Africa (ECSA) that all engineering graduates be exposed to complementary studies which, inter alia, broaden the student's perspective in the humanities, social sciences or other areas to support an understanding of the world (University of Cape Town Faculty Of Engineering & The Built Environment Undergraduate Handbook 2017).

These are the exceptions however, and taking one arts course out of scores of engineering courses may not have much effect on a student's future working life, particularly since the new recruit will be initiated informally or formally into company practices. Pragmatically, an engineering student must complete a curriculum fit for engineering, so to suggest greater liberal arts content at university level may not be sensible, although there are some medical schools that insist on doctors spending an entire year studying, or working, entirely outside of the medical field.

In many respects we are binary creatures, as if a biological, cerebral division is encouraged and taken as physical reality in the world at large: are you left-brained or right-brained; male/female; black/white (significant in South Africa); an arts or a science graduate? As any social anthropologist will attest, those who, or that which, crosses these arbitrary and socially constructed boundaries are taboo by definition (Douglas, 1966). Ambiguity is not tolerated, from those of alternative sexual persuasion, to those of mixed race in South Africa: ambivalence and boundary-crossing are discomfiting. People must be male or female, black or white, artists or scientists, and not both at the same time. This pervasive fear of liminality and the highly contingent notion that education must be ordered into two categories breeds the inability to face and solve problems which are both technological and sociological.

Centuries of academic discourse on the complex relationship between society and technology passes the technologists and engineers by, generation after generation. Of course, this phenomenon isn't limited to engineering and the space community. The space industry is not alone in having a distant relationship to users, in only considering superficial aspects of use cases, or in working for intermediate entities who may not consider the human user important, *even though it is the human who ultimately spends the money*. Evidence for this can be found in many quarters: car-centred town planning leaves those on foot stranded in distasteful and dangerous wasteland areas between roads; aircraft are built in order to compete for carriers, not for customers who are sardined into them and deprived of decent air; kitchens are designed by architects to look good, not for those who have to maintain hygiene and feed a family in them. End users are often treated as problematic, even in the software

industry, which has been held up as an example for the space industry to follow in this study.

Some would go further, and declare that it is of necessity that institutions and organisations contain within them the opposite of what they purport to be and do. That a space industry so hell-bent on speed and escape, breaking new ground, the ultimate in exploration, should be internally sluggish, reluctant to change and hide-bound in its orthodoxy, betrays *institutional shadow*. Hollis (2008), along with many other Jungian analysts, demonstrates how it is that society's institutions as well as individuals, contain within them opposing forces, which can become the seeds of their own demise. A person's shadow is that which he or she hides from themselves, often the very opposite features to those they display to the world. Institutions similarly act out their shadows in *false consciousness*[5], impacting society with actions borne from the opposite values to those which they purport to uphold. Governments outwardly intend to serve their people, yet plunder the public purse in pursuit of self-interest through corruption, nepotism and greed; schools snuff out a child's natural curiosity about the outside world, as can be witnessed through the building of structures with high walls and windows, with punitive pedagogical practices that instil in the child a loathing of learning and inuring the child to boredom; hospitals are unhealthy places to inhabit especially when sick. The space industry, for all its *braggadocio,* fears risk and change. As Hollis pointed out:

> 'Underneath the civilizing fantasies of any institution lie the archaic issues of anxiety management and self-interest. When these two threats are activated, institutions, like individuals, tend to regress and abandon their founding vision' (Hollis, 2008).

The reason quoted by space engineers for their risk and change aversion is that at the core of space mission design is the need to retire risk, obviously needful when expensive rocketry has a high chance of destroying the client's payload before reaching orbit. Technology Readiness Assessments form the basis of procurement decisions whose sole purpose is to ensure that whatever components are used have

[5] A term coined by Marx where the true nature of a political or social situation is occluded by displaying opposite characteristics, often perpetrated by symbols.

already been used before. By contrast, heritage, in the IT industry, is anathema. Not only is it costly and high risk to have to deal with legacy systems, but the IT industry needs a high rate of obsolescence in order to progress. Operating systems and application software must be upgraded frequently to keep customers coming back for more. This is not only because the technology itself is immature (as would be the response to Technology Readiness Assessment), but also because it makes sound business sense. It would be unthinkable for IT companies to create a product that never needs to be tampered with, replaced or refreshed.

Interestingly, in terms of this line of enquiry, a need to honour the pragmatism of space heritage does not preclude changing business and development practices. It is possible for the Space Mission Analysis and Design (SMAD) process to honour its reliance on Technology Readiness Assessment and space heritage, whilst taking novel and unfamiliar approaches to user requirements determination. After all, it is only likely to be the payload that may change if users are better consulted, not the rocket, launch, and ground stations. The mighty tomes of the ECSS manuals, printed and bound and on chief engineers' shelves, are not there by birthright. Inertia and fear of change keeps them there, fastened to the wall. As shown in Chapter 4, the IT industry doesn't care for space heritage, and isn't interested in tried and tested methods: it will cherry-pick from current engineering practices and products whatever works for the moment. By contrast, the space industry's sluggishness looks like institutional shadow at work.

For all the criticism of space engineering and its reluctance to embrace risk and change, it is increasingly the IT or data industry which turns space-derived data into products, even when the IT industry has not had the opportunity to specify characteristics of that data. The IT industry does not suffer from historical baggage or myopia. It can nevertheless be criticised of cultural homogeneity.

6.4 Where does this leave space applications for Africa?

As stated in Chapter 2, the hypothesis in this study is that, by relegating the user concept and focusing only on client requirements to drive satellite design, the space industry is missing large potential new markets for space-derived data, and

inadequately specifying payloads. The implication is that large potential new markets could be found in Africa if a fresh view of users were taken.

Since there has been a large body of work in the field of ICT4D, which is highly user orientated and where there has been plenty of focus on Africa, why hasn't this resulted in applications appropriate to the African continent? We remain in a situation where space images exist but are not utilised, and many needs exist which are not addressed but could be, by appropriate space missions. This situation persists despite decades of research in ICT4D.

The immediate response is poverty, and that space missions and high tech are costly. But this doesn't fully answer the question of why ICT4D has not produced sustainable results, particularly given the large size of potential markets. Bill Gates, co-founder of Microsoft and co-chair of The Bill and Melinda Gates Foundation, encapsulates the answer:

> '… there are few one-size-fits-all solutions. If technology is going to improve the lives of the world's poorest, it must be grounded in a deep understanding of human behavior and an appreciation for cultural differences' (Gates, quoted in Toyama 2015).

Toyama is a critic of ICT4D, deeming it populated by those with self-serving, often technocentric agendas. His polemic book *Geek Heresy* attacks those who believe that answers to problems lie in technology alone. He lists what is really required to change the world:

> '…we should focus on those goals for which technology and technocracy are ill suited: serving poor communities, educating the less educated, reforming dysfunctional institutions, organizing marginalized groups, preparing for long-term crises, encouraging self-transcendence, and eliciting responsiveness from those in power' (Toyama 2015).

These all require long-term relationships, not the quick fix of a project that fits into an academic calendar in an institution far away from the communities it researches but does not serve.

If ICT4D has not produced satellite-based solutions to social problems, and African space agencies and governments are too poor for the investments required to create the space technologies required for the continent, commercial interest and disruptive innovations may provide a way forward. As mentioned in Chapter 4, many of the new disruptors of the space engineering world are situated in Silicon Valley, California, and are no different to the IT start-ups that fuelled the dotcom boom. Making financial profits is not the only motivation for high-technology start-ups. As described in the BBC documentary *'Secrets of Silicon Valley'*, Episode 1: The Disruptors (2017), there is an element of building a better world to many of the activities of disruptors. For all the justified cynicism of commentators such as Toyama, many technologists are keen to have their innovations used for public good.

7

7 Concluding remarks and recommendations

The problem explored in this study is that the space industry develops products that are not what end users want or need, and in this manner distracts itself from developing products that might be useful to more people. The chief reason identified for this problem is that there is usually a large gap between end users and those who design space missions and satellites. The answer then appears that this gap should be narrowed. However, the structure of the space industry means that it is difficult to narrow this gap. The space industry creates space technology and artefacts for others to utilise, in particular the IT industry. It is the IT industry that develops applications for the end user that can take advantage of the technologies offered by space.

There are secondary problems that make it difficult for the space industry to address this gap, and these are further reasons offered by the space industry itself for the problem described above:

- The need for low-risk technical approaches
- The time it takes to create an artefact that will be launched into space
- The overall cost of development, deployment and operations
- The need to settle on a particular technical configuration and componentry relatively early on in the design process

The gap between end user and space technology developer is unlikely to narrow unless applications developers become the clients, or themselves become space developers. As we have shown, this is happening with disruptive innovation, where many space start-ups are located in Silicon Valley and have arisen from an IT background, and act more like IT organisations than space engineering companies. As the space industry commercialises and is put under more pressure from disruptors, it will adapt: shorten design cycles, re-examine its methods, and shake off its cultural inertia.

We have also critiqued the development methods employed by the space industry in how they approach users, and compared the space industry with the IT industry in

how it treats users. In particular we examined the design methodologies and architectures employed in the IT industry quite closely to see what can be learnt about different approaches, and whether there is anything useful that the space industry, at least satellite developers, could learn from the IT industry. However it was difficult to conclude that the more agile and cyclical development methods of the IT industry could be applied to space, where the chief mode is of a mission with essentially one end product, rather than a continuous development exercise.

Governments, who are often the clients specifying space technologies, have no feedback loop that shows whether money has been wasted in the past, and may again be wasted. This may never come to pass, since what constitutes wasteful expenditure in a political context is highly contingent on the moment, and that feedback loop, when it involves end-to-end design, deployment and user reactions, takes several years and perhaps longer than a usual political term of office. In addition, the subject is fairly esoteric and unlikely to provoke public response, and governments rarely change tack unless driven by the public or some major external force. A government can always justify the claim that it has discharged its responsibility by providing funding for what can always be couched as human capital development, industrial stimulation, or in the case of parastatal space industries, job creation.

The driver for change, and for better user-responsive space, is commercialisation. This also breeds a broadening of the space industry to incorporate, or be ousted by, the IT and data industries, who are now encroaching into space territory. These industries are not affected by traditions and ways of thinking and working that preclude change. This may result in technical debt, as covered in Chapter 4, but some alternative organisations will prevail to become the dominant forces. There is no recommendation here beyond watching as business dynamics play out.

Engineers and developers are in a position to be more connected to the user and to take a wider view of what constitutes user requirements and how these devolve into technology offerings. Unfortunately they are not trained in thinking beyond the technocentric and have a primary imperative to satisfy the client. This client also employs engineers as specifiers, and they themselves have other clients, often government, and the individuals in the long value chain are likely to be all engineers

or technologists. These highly trained technical people have necessarily received a blinkered education and are unaware, in a very fundamental way, of the world outside their offices and the opportunities it affords.

The reason for Africa and other developing countries being poorly served by satellite technologies is not only because they are poor and cannot afford them. The majority of people on Earth live in developing countries, and now that we have the means to carry out microfinance and microtransactions, there are fewer monetary obstacles to delivering services to the poor. However, the technologists, developers and specifiers of space systems do not understand the lives of the poor. Nor are the clients and intermediaries able to create business models for situations with which they are not familiar. Africa represents the second-largest land mass on the planet with the second largest population, and as such ought to be well-serviced by satellite imagery and other data and space-derived services, but the opposite is true.

As an industry, space is far from adding cultural heterogeneity into its business models. In terms of Africa and what to do about the dearth of space activity and provision, there is only one recommendation. Changing the political *modi operandi* of African national governments is not going to happen with alacrity. Neither will the engineering curricula of universities become sufficiently broad for engineers to incorporate sociological approaches to design (if this is indeed desirable). We need more diversity in the space industry: more women, more people from different cultural backgrounds, and most importantly we need to honour their differences.

Any social grouping, deliberately or unconsciously, impacts individuals, forcing or encouraging them to conform and reproduce group norms, values and behaviours. Perhaps something can be harvested from the non-conformists before they become acculturated into the space engineering world, and turn up for work in checked shirts and chinos, a fleece when it's cold: a uniform of navy blue, beige, and occasionally bottle green. Perhaps their viewpoints and suggestions can be taken seriously, and then perhaps the woman with a hoe in her *gomesi* will be seen as a consumer of space services and not as somebody else's problem. This could be the goal of social and political transformation: not merely to ensure that previously disadvantaged

individuals gain career purchase in areas once precluded from us, but that our differences are celebrated and alternative knowledge harvested. To capture the 'knowledge features' of people who are not typical space engineers is the task. As the UN's World Social Science Report states:

> 'Inequalities are multi-dimensional, multi-layered and cumulative. The Report makes clear that understanding and acting effectively upon inequalities requires looking beyond income and wealth disparities to capture their political, environmental, social, cultural, spatial, and knowledge features. Untangling such complexity is a challenge we must fully take on – if we are to develop policies and solutions that are feasible and sustainable' (UNESCO and ISSC 2016).

Figure 7.1: *Indian Space Research Organisation engineers celebrate the launch of the Mars Orbiter spacecraft. Credit: AFP News Agency.*

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