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Watchpoints for Consideration When Utilising a VDI Network to Teach Archicad BIM Software Within an Educational Programme

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Watchpoints for Consideration When Utilising a VDI Network to Teach Archicad BIM Software Within an Educational Programme

Malachy McGarrigle

Abstract

This research identifies factors to be considered in the adoption of a virtual desktop infrastructure (VDI) accommodating the software needs of a tertiary institution. The study discusses the potential advantages and disadvantages of VDI, focusing specifically on the performance of the architectural software Archicad when used virtually. The findings will be relevant to similar programmes, such as Revit, and software used in other disciplines, especially where processing power is important. Aims discussed include reducing high-specification computers rarely used to capacity, assessing user experience, and feasibility of VDI remote access. Primarily a case study, this project centres around delivery of papers in the New Zealand Diploma of Architectural Technology programme at Unitec | Te Pūkenga that employ Archicad. Software efficiency and performance was monitored throughout teaching across numerous semesters. Incidents were logged and VDI operation tracked, especially during complex tasks such as image rendering. Load testing was also carried out to assess the implications of large user numbers simultaneously performing such complex tasks. Project findings indicate that Archicad performance depends on the design and specification of the virtual platform. Factors such as processing power, RAM allocation and ratio of users to virtual machines (VM)s proved crucial. Tasks executed by the software and how software itself uses hardware are other considerations. This research is important, as its findings could influence the information technology strategies of both academic institutions and industry in coming years. Virtual computing provides many benefits, and this project could provide the confidence for stakeholders to adopt new strategies using VDI instead of the traditional approach of computers with locally installed software applications.

Introduction

This research project developed from a decision taken by Unitec | Te Pūkenga to roll out a virtual desktop infrastructure (VDI) to meet the software needs of its lecturers, administration staff and students. The research aims to generate findings to inform the deployment of VDI across Unitec in other departments, especially where specialised software is crucial to enabling students to achieve necessary learning outcomes. Very limited initial consultation had taken place with the author or colleagues on whether sophisticated professional architectural software such as Archicad and Revit used to teach in the New Zealand Diploma of Architectural Technology programme (NZDAT) would run when provided on a VDI system. Changes in approach were made, and this paper presents the detailed discussions and testing carried out in collaboration with Unitec information technology (IT) colleagues with regard to how the specific software Archicad performs across a VDI.

This was important, as the initial roll-out of the VDI system included computer laboratories where the programme was taught. Archicad and Revit are currently the foremost packages used in architectural practices across New Zealand; therefore, having functioning resources to help train students is of vital importance. This paper started out as a feasibility study, but since the decision to adopt VDI across Unitec had already been formally taken, evolved into a case study to see how the system could be used most efficiently to serve the needs of both Unitec and its end users, especially students.

The scope of this research study is that it is intended for tutors who could be teaching in a variety of discipline areas, whether construction, architecture, design or music. The paper is not intended as a detailed analysis of all the components required in the creation of a virtual design platform in an institute, as it is assumed that IT staff would address those areas of VDI design and provision.

The limitations of our research project were that it dealt solely with providing Archicad software access via the virtual desktop using Unitec computers on campus. While remote access was discussed and requested by some students, the performance of the platform was not tested remotely. However, informal feedback from students who requested this and were provided with such a service was positive, and gave promising indications for future provision. This research case-study related only to two courses within the New Zealand Diploma in Architectural Technology, and Archicad testing was limited to the outcomes requested of students in the assessments for these courses.

The educational context of the majority of research projects reviewed in literature was at tertiary level, mainly undergraduate, but some also on courses towards master's level qualifications. One exception found in literature was where the study was carried out in a primary school in China (Xu et al., 2015), but this exercise was an overarching project investigating suitability for the whole school network, and did not focus on particular discipline areas or specialist software the way our project did.

Many of the studies in the reviewed literature adopted the same approach as in the Chinese primary school, in that solutions were sought via testing for VDI platforms that would be general across an institute, at least for initial deployments, and often involved supporting college administration and management systems (Alharthi et al., 2015). An add-on to this approach was to further consider the sustainability and green benefits, but, again, without regard to specific qualifications or individual papers leading to final awards (Agrawal et al., 2014; Hossain et al., 2020).

The other notable factor in the educational contexts of papers reviewed was whether the research was carried out remotely online, or tested in a traditional classroom set-up or similar scenario. A lot of papers analysed VDI platform performance when delivered online, as many studies were in response to the restraints put on the education sector during the Covid-19 pandemic. This approach is very appropriate, following recent world events, but it differs from our project, which primarily investigated the VDI performance using specific Archicad software when accessed through computers on campus.

The intention of the research is to use the results of the investigation to inform the deployment of VDI across Unitec in other schools and, in particular, those where specialised software is a crucial means of enabling students to achieve the learning outcomes necessary in their qualifications. Due to the wide range of software required in labs across Unitec – the School of Building Construction alone has identified some 12 different programs necessary to teach their courses – and lack of resources, including time to test all of them on the VDI system, this study concentrates solely on testing of the Archicad model-authoring package.

A VDI replaces traditional desktop operating systems on local PC machines through virtualisation technology providing access to operating systems and other services and applications hosted on a centralised server in a data centre. It is a variation of server-based computing, and basically means that in a typical computer laboratory where the VDI system is installed, the students do not have a traditional desktop computer at their workstation but rather a significantly smaller device measuring approximately 225 × 240mm × 40mm deep, which can sit on the work surface or be suspended below the desk.

VDI is an approach to providing access to software, including sophisticated applications, that has been widely considered within both industry and the education sector in recent years. Literature has pointed out many advantages, including the cost and sustainability benefits that accrue from providing the software to clients where the terminals at the user end are fairly simple devices accessing the professional-level application installed on a central super-computer. Other benefits highlighted include the central management and control of the computers used in the computer studios linked to the network, increased security, reduced need for maintenance, and the longer lifecycle of the devices utilised by students, due to their simplicity when compared to the high-end computers often provided in teaching labs at present. System upgrades are also seen as easier to manage and execute using VDI. The VDI system is also considered more efficient, due to the fact that, at present, most high-end computers are rarely used to their full capacity in terms of things like graphics cards and memory being called upon, for example to produce high-quality photographic renders in architectural software. VDI has been considered and trialled in education and also in the health sector in Korea, where iPads were employed to access a central data base as opposed to actual software packages.

The benefits and barriers of VDI are discussed in more detail in the literature review.

Literature review

In terms of educational context, as stated in our introduction, much of the research into VDI platform deployment in education to date has been carried out within tertiary education institutes. One project did centre on a primary school in China, but it differed from this study's approach in that it was a general analysis of the benefits of using VDI to provide services school wide, without providing any details on specific discipline areas, courses or required software (Xu et al., 2015).

Some papers did not state any type of specific educational context at all, and concentrated mainly on detailed discussion on the elements of a VDI platform (Chang et al., 2020). Chang et al.'s (2020) paper covers a great deal of technical detail regarding how to provide GPU performance on a virtual machine (VM). This approach differed significantly from our project, as our intended readership are lay tutors who would not typically be IT specialists, and who may be put off by a lot of technical jargon. No specific tasks were highlighted for the testing in this paper, although benchmarking tools are referenced. Another paper used a similar nonspecific approach, which lacked mention of any course or classroom context but did set up baseline tests to evaluate the performance of some software, such as antivirus solutions and Microsoft Office for students (Nehra & Kumar, 2020).

The other major difference in approach to our project adopted by many studies in the literature was that, whereas our study concentrated on examining VDI provision and performance on campus, a lot of the papers in the literature were centred around provision of services and resources online. These papers typically studied a VDI platform set up in response to the challenges of teaching during the Covid pandemic. Storage, resources and software were set up on a VM system designed to enable remote access to the resources stored on the VMs (Alsadoon, 2022; Calle-Romero et al., 2020; Sola-Guirado et al., 2021; Rodriguez Lera et al., 2021; Alzoubaidi et al., 2021).

Of the higher-education, college-centred research, a lot of papers covered similar aspects regarding the benefits of VDI, such as improved security, privacy, internet efficiency and ability to access remotely, but many of these discussions were quite general and did not identify more specific academic contexts in relation to individual papers within qualifications and discipline areas, or particular specialist software that may be necessary (Alharthi et al., 2015).

Some studies did go into more detail regarding the educational contexts of their research, with a Polish paper analysing a large VDI platform of 240 terminals and 400 virtual systems to be used in a university of economics.

Software related to the actual VDI provision, such as VMWare and Citrix, is stated but there is no mention of any software, or particular class or course (Chrobak, 2014).

Other papers went further in listing software to be employed, but testing did not form part of any ongoing teaching and no course or classes were stated. The software packages were often grouped into various scenarios, and one of these sets included a video media player and picture viewer. This software-analysis approach was one of the closest to the graphics testing studied for our Unitec paper (Nakhai & Anuar, 2017). A paper from Saudi Arabia based on a tertiary education provider centred around online provision country-wide. It did, however, have some similarities to our study, in that it discusses a teaching model of lecture followed by lab work, which is the same as the approach used in the discipline-specific papers in our project (Alsadoon, 2022). This paper canvassed student responses via an emailed e-questionnaire, which was a more structured approach than the informal student feedback comments sought in our study. A Japanese study of unclear educational context looked into various activities and tasks executed across the VDI, one of which involved drawing in PowerPoint (Nakazawa et al., 2012). The authors also examined the effect of network quality on things like typing and mouse movements, and this approach is similar to our own, where we also tested things like mouse scrolling to zoom in and out of our Archicad digital model.

A project based in a Florida college of art and design, though dated, still appears very relevant, and their on-site testing of the VDI is similar to the on-campus provision for our study at Unitec. Specific software is identified, including Maya and Architectural Desktop, and another important factor noted is that some software applications at that time were not designed to be provided virtually. This mirrors our experience, as the developers of Archicad state that they do not intend for their software to be deployed using virtualisation (Miller & Pegah, 2007). This paper highlights operating system and hardware dependencies, which aligns with the finding we discovered regarding Archicad's use of a CPU when executing complex tasks, such as three-dimensional photo renders. This paper also tested Adobe packages, such as Photoshop, and an intention of theirs that echoed our own study was to examine the end-user experience.

A paper from the University of Cordoba discussed some tasks that were basically the same as some required of our students; namely, topographical modelling and rendering (Sola-Guirado et al., 2021). The class under study was a master's level engineering cohort and the software included Autocad and Solidworks, professional packages of a comparable level of sophistication to the Archicad programme used in our teaching and tests. The students in this paper accessed the VDI through their own personal computers, which differed from ours, where the students were given access via on-campus institutional computers. Some Unitec students still preferred to bring their own laptops, but accessed Archicad via local machine install. The Spanish students' feedback on using VDI was very positive, with a score of 3.89/5, although, interestingly, many of them still opted to install the software directly onto their own laptops (Sola-Guirado et al., 2021).

Earlier literature omits aspects such as potential VDI software-update issues, though more recent studies address these (Lee et al., 2021). Most testing in the literature was done after system deployment, but none was done during VDI development to inform final platform set-up. In some instances, the study sought not to test the VDI system itself, but rather to determine what effect the new teaching method may have on student results (Sola-Guirado, 2021). One study, however, did very detailed simulation testing with an architectural practice, recording similar data to the tests in this paper (Lee et al., 2021). There was little evidence of how end-user briefing discussions were carried out to generate VDI proposals meeting software performance requirements. Cost discussions focused more on savings rather than capital and running costs, and very little information assessed VDI system architecture, such as CPU cores or speed needed for specific architecture, engineering and construction (AEC) demands. One paper did focus, however, on using VDI for building information modelling (BIM) in an architectural practice (Lee et al., 2021).

FLEXIBILITY OF VDI ENVIRONMENTS

A number of papers highlighted system flexibility as a benefit of the VDI approach, and one emphasised the significant impacts foreseen on how users interact with computers, both at present and in the future (Berryman et al., 2010). VDI as a variation of cloud computing was also discussed in a number of papers, with aspects mentioned including the capacity of this internet-based approach to offer a range of on-demand computing services while permitting clients to scale up or down the services they required (Alharthi et al., 2015; Chong et al., 2014). The ability to choose between whether the computer-room environment offered similar desktops or bespoke software choices relative to the characteristics of the subjects being taught was another important benefit noted in literature (Nakazawa et al., 2012). It is not only possible to have pools of VMs that host desktops with the required software, but also to define user groups who share application sets while retaining distinctive data sets (Berryman et al., 2010).

SYSTEM MANAGEMENT

This topic, and how a VDI system accommodates the tasks necessary, was the most frequently occurring theme in the literature reviewed. It provided discussion on many areas across papers and addressed matters such as loads experienced and ability to monitor the health condition of the system. The ability to efficiently manage server resources based on CPU and memory demands was highlighted, while the benefits of system flexibility and user groups mentioned above was also stressed strongly in management terms (Berryman et al., 2010). The use of connection brokers to allow end users to log in to the relevant software suites for their courses and the ability to provide VDI images on the server customised for user pools was a frequently quoted advantage of a VDI system (Berryman et al., 2010; Chrobak, 2014; Harbaugh, 2012; Miller & Pegah, 2007). The low utilisation of high-performance graphics workstations, especially machines frequently specified to meet an application's minimum operating requirements, was a common item discussed, in tandem with VDI's ability to mitigate this potentially costly scenario (Harbaugh, 2012;

Miller & Pegah, 2007). System maintenance and VDI's ability to simplify and improve upon traditional approaches was observed to be a noted advantage over previous practice. Maintenance worries were reduced, due to central management of the operating systems in the data centre, leading to a more productive and efficient IT organisation.

Operational efficiency was also noted as contributing to higher cost savings (Lee et al., 2017). The variety of typical issues to be resolved by IT technicians, such as constant updating of applications whether for the internet or antivirus systems and including installation of operating-system patches, often resulted in what one paper termed a "break–fix endless loop" (Chrobak, 2014, p. 3). Server infrastructure is seen as capable of providing a range of services, such as storage, computing ability through virtualisation, system resource management depending on available tools, isolation and security, improved performance and platform support, and migration options. Maintenance and management are seen as being easier due to the fact that multiple separate operating-system images and various associated, including specialised, software applications share a single server, with users upon login accessing separate VMs. Processing workloads are migrated from single lab workstations to centrally located and managed enterprise class servers, permitting simplified administration and maintenance where one person can maintain some 500 machines, as opposed to only 50 during the 1990s (Chrobak, 2014; Liu & Lai, 2010; Miller & Pegah, 2007).

COST FACTORS

Many fiscal benefits are attributed in the literature to VDI compared to traditional computing services provision. Examples were savings in power consumption, infrastructure, networking and overall maintenance costs due to VDI workstation consolidation mitigating low utilisation issues noted previously (Miller & Pegah, 2007; Nakazawa et al., 2012; Hossain et al., 2020; Sola-Guirado et al., 2021; Rodriguez-Lera et al., 2021). Reduced costs to educational establishments are highlighted, resulting from fewer expenses in procurement and maintenance, and overall IT operational fiscal expenditure (Chong et al., 2014; Xu et al., 2016; Nehra & Kumar, 2020). Potential savings were identified in many areas and the economic and organisational cases for implementation of VDI into academic institutes were justified by stating up to a 75% reduction in hardware costs and 90% reduction in the user's energy footprint. (Agrawal et al., 2014). It was noted that devices produce little heat, thereby reducing air-conditioning costs, and VDI was claimed to consume only some 25% of a typical workstation's power, including the monitor. Even after consideration of server-side power consumption, it was stated that power savings of 50% were not an unreasonable expectation. Thin client VDI systems were stated as some three times cheaper than a typical PC executing the same tasks, and aspects such as reduced infrastructure costs added to limitation of energy consumption and waste; these factors were all seen to contribute to a lower total cost of ownership using VDI (Agrawal et al., 2014; Chrobak, 2014).

REDUCTION IN UNDERUTILISED DESKTOP WORKSTATIONS

Dramatic reductions were predicted due to avoidance of high-end, high-spec machines sitting in remote office corners being called upon for only a fraction of their functionality (Nakhai & Anuar, 2017; Alzoubaidi et al., 2021). These could be replaced by only such VDI hardware necessary to permit student production of the work required in their courses (Chong et al., 2014). This was a theme that occurred in various papers and it did not only apply to classrooms, but also to computer laboratories, where low utilisation was again demonstrated by fast computers not being used to their full functionality (Chrobak, 2014; Hossain et al., 2020). It was stated in one paper that most users in the higher-education college studied did not avail themselves of the entire capabilities of their computers for their regular work. They typically required only around 5% of the potential capacity of their workstation, while the majority of applications required only a small portion of some computers' actual capabilities (Agrawal et al., 2014).

IMPROVED MOBILE AND REMOTE ACCESS

This theme relates to VDI end-users such as students being able to access applications relevant to their course by logging in to the VDI system across various campus locations, such as in a library. A future development of this model envisages that students would actually be able to gain access to learning resources, such as required qualification software, by logging in at home or even on the move (Berryman et al., 2010). Another important point that also relates to end- user satisfaction regards the potential freedom of a student or office worker to decide whether they want to access the VDI platform from home, school or office, at any time, and on a device of their own choosing (Nakazawa et al., 2012).

IMPROVEMENTS IN DATA SECURITY

This was another theme that figured prominently in literature across some five papers. Factors emphasised were those such as security being enhanced due to the fact that no actual confidential client data resides on the end-user terminal (Berryman et al., 2010). Because potentially sensitive data is stored on the server, copying of such material to local devices can be prevented. Another advantage is that if a local device is stolen, no sensitive or confidential information will be lost (Chrobak, 2014). A VDI platform provides security and flexibility depending on system set-up; typically, users will have no control over infrastructure but will be able to control the applications used through the infrastructure (Chong et al., 2014; Xu et al., 2016). Despite the benefits discussed in the literature, it was also pointed out that VDI does pose new challenges around data protection and platform security from both internal and external threats. Existing measures such as firewalls and other security tools monitoring intrusions and abnormal behaviour cannot in theory detect traffic occurring in the physical network, and therefore their effectiveness and efficiency is reduced. For example, to mitigate the risk of an infected VM spreading the issue to others, measures such as ensuring all VMs are running the same operating systems may be necessary, or the development of a new VM-specific approach to security architecture (Liu & Lai, 2010).

ENHANCED END-USER EXPERIENCE

The impact on the client using the computer services, in terms of quality of experience, is another substantial discussion point in the literature. This is usually based on the effects, if any, on terminal performance when compared to traditional workstation provision. It is stated that if a VDI solution is cumbersome to use and doesn't at least equal the traditional experience that users have come to expect, then acceptance will be difficult (Miller & Pegah, 2007). The technology is seen, however, as generally reliable, being fault tolerant and highly available, with on-demand individually tailored application suites making a more user-friendly client experience highly possible (Chong et al., 2014). VDI system memory is mentioned as possibly the most contentious and costly element of the system, but its impact on whether software would perform as expected and required is made very clear. Also emphasised is the importance of server-side performance in supporting a satisfactory end-user experience, and how this is crucially dependent on the condition and health of the network (Alharthi et al., 2015; Berryman et al., 2010).

TESTING APPROACHES FOR VDI PLATFORMS

This is a theme that frequently occurs in the literature, and the relationship to network health and condition is highlighted for its potential impact on results. Bandwidth and system speed are noted as significant factors, as is the need to execute the "traditional IT cycle of evaluate, test and adopt" in order to identify critical performance issues, keep customers working efficiently and maintain effective workflows (Agrawal et al., 2014; Miller & Pegah, 2007, p. 5; Nakazawa et al., 2012). Papers used metrics such as latency (delay), jitter and data-loss rate, with the concept of round-trip time used in one to measure the time necessary to execute operations in a PowerPoint file, such as typing in data and using various mouse commands (Nakazawa et al., 2012). A key objective of many studies was to determine the effects on the host server while experiencing loads generated by tasks executed by typical users on the client side. Loads were devised to test software response times and also interaction times with the software in use by clients. A main goal was to maximise utilisation levels of the host resource to positively influence interaction response times of applications on VMs in use by clients. The testing set-up and configuration was highlighted, as was the point of how dependent the VDI platform would be on either an intranet or internet. One benchmarking approach sought to simulate thin client user-activity demands and analyse the effects on what it termed "resource consumption characteristics" (Berryman et al., 2010, p. 8).

PERCEIVED BENEFITS OF VDI

The majority of literature is in favour of VDI, and many benefits are highlighted across a number of papers. Cost saving in areas such as capital expenditure, reductions in IT staff numbers, infrastructure, power and maintenance costs were all frequently identified. The agility of a typical VDI system was highlighted, as was its ability to offer high-performance workstation graphics capabilities at client end in a variety of ways, whether low-end desktops, notebooks or via thin client devices (Chong et al., 2014). A VDI system is seen to encourage standardisation and simplify sharing, while reducing unused computing capacity. Advantages cited include disaster recovery, robustness, scalability and security, all features that add to the attractiveness of the model (Chong et al., 2014; Miller & Pegah, 2007). VDI systems are seen as easier to deploy, manage and maintain, while offering longer life-expectancies and centralised data-storage in a protected environment (Agrawal et al., 2014). VDI helps companies integrate IT resources, with less time taken up in deployment, security and fault isolation, and easier software updates and security patches. Efficiencies are envisaged because hardware development is stated as typically outpacing software development, thereby reducing effective utilisation of a network system's potential. This point is also reinforced by the sustainability benefits possible with VDI, due to average CPU use levels being low across a VDI, leading to resource efficiencies and energy savings (Liu & Lai, 2010). VDI thin client equipment taking up less physical space is stated in numerous papers, leading to agreement with others about the green benefits of the approach in relation to aspects such as carbon footprints. VDI is also seen to be faster than imaging technology, permitting connections to devices, whether Apple, Linux or Windows, while not becoming obsolete as quickly as PCs. Traditional workstation amortisation times of three years are seen as being pushed out to five years, due to the lack of user-end equipment such as processors, graphics cards and disk drives. Mean time between failures is projected to extend to 70,000 hours, as compared to a workstation's 30,000 hours, leading the University of Wroclaw in Poland, after some two years of tests, to conclude that "VDI promises more efficient use of the University's resources" (Agrawal et al., 2014; Chrobak, 2014, p. 7).

GAPS IN THE LITERATURE REVIEWED

Earlier literature omits aspects such as potential VDI software-update issues, though more recent studies address these (Lee et al., 2021). It was difficult to find literature discussing matters such as program patches, which, if unavailable, could necessitate updating the virtual computer image with the revised software application. Making changes to a system provided by an external vendor can be expensive, and a basic fee of over almost $2,000 dollars was a typical fee quoted to Unitec in early iterations of their VDI platform.

Most testing in the literature was done after system deployment, but none was done during VDI development to inform final platform set-up. One study, however, did very detailed simulation testing with an architectural practice, recording similar data to the tests in this paper (Lee et al., 2021). There appears to be little evidence of how end-user briefing discussions were carried out to generate VDI proposals that met software-performance requirements. The whole briefing process, in terms of establishing what end-users need from the system, is not explicitly detailed in any paper, and certainly not in regard to the performance required of any specialised and sophisticated AEC applications such as Archicad or Revit. This applies also to using software to produce evidence such as drawings to satisfy learning outcomes. Cost discussions focused more on savings, rather than capital and running costs, and very little information assessed VDI system architecture, such as CPU cores or speed needed for specific AEC demands. One paper did focus, however, on using VDI for BIM in an architectural practice (Lee et al., 2021).

Methodology

The academic context to this research is two papers contributing to the New Zealand Diploma in Architectural Technology Level 6 award, namely the Level 5 papers Scoping and Preliminary Design, and Documentation for Small Buildings, typically studied in the first year. In an international context, this New Zealand Diploma award equates to Level 5 Higher Professional qualifications on the European Qualifications Framework. Qualifications are typically 120 ECTS (European Credit Transfer and Accumulation System) and aim to prepare learners for employment (ANQEP, 2016). The methodology included informal monitoring of the Archicad software performance in use during teaching of the above papers, semi-structured interviews with various professionals such as architects, Unitec IT staff and various external IT vendors, and basic and specific testing designed to replicate on Archicad the tasks and model outputs necessary to satisfy the course learning outcomes. Basic tests involved opening up and using the software to initiate a project from a template file by creating simple walls, roofs and slabs, whereas specific tests included tasks carried out on more developed house projects, such as generation of photo-rendered views.

The informal monitoring consisted of recording any incidents that occurred during teaching of Archicad in the VDI lab, and noting the context and circumstances in terms of what students were trying to achieve with the software, and active numbers using the VDI platform at the time. This was a fairly basic incident-logging process and was not actually required on many occasions.

The semi-structured interviews were carried out with five participants. All the interviewees have extensive experience in the construction industry directly relating to computer-aided design (CAD) and its more recent term, building information modelling (BIM).

Three interviewees were from architectural practices, one was a VDI system vendor and the other was a Unitec IT staff colleague directly involved in the deployment of VDI across the institution. Interviews were held either in person or, where this was not practical, by telephone. Interviews were not rigidly structured, and though questionnaires were employed, these were used primarily as a starting point for the dialogue.

Interviewee 1 had worked in architecture for some 17 years, with overall construction experience of 23 years. Recent roles have all concentrated on digital design responsibilities, with this person being a digital principal at two architectural practices in Auckland over the last almost seven years to 2023. Prior to that he was product manager at a BIM software company in Auckland. An aim expressed by this person regarding his company moving forward was to “exploit digital workflows using devices such as smartphones and enabling staff to work outside the office." VDI was seen as one way of providing the ability to work in a more flexible manner, although, as is typically the case, "Cost is a prime consideration in coming to any decision."

Interviewee 2, from Australia, is currently director of a company that provides VDI for the construction sector and claims capacity to "deal with demanding software and large files" using solutions tailored to the specific requirements of individual companies. This person has been involved in architecture since 2002, and other roles in that time include working as a university teaching fellow and on large-scale projects up to AU$900 million. This person stated that client discussions towards articulating objectives were part of initial deliberations, and it was necessary to have "briefings with firms to reach outcomes at price points." In terms of the practicalities of establishing a suitable VDI platform for an AEC company, "getting time and resources to carry out adequate load testing was an issue and testing on VDI environments can be tricky."

Interviewee 3 is a former Unitec student who has worked as an architectural technician for more than five years up to 2023. He has over 20 years' experience working with Autocad, including spells as a business development manager for an Autodesk supplier in France following a similar role for a company in Auckland, New Zealand. His most recent position is as an architectural technician with one of the leading companies in New Zealand, which uses high-end model authoring software extensively in their work. Part of these discussions covered cloud computing solutions, with the person stating that in their company they already employ "BIM 360 for certain uses, such as colleagues collaborating on large projects."

Interviewee 4 is a director of an Auckland architectural practice that specialises in providing BIM services to clients. He has almost 30 years' experience in the construction sector, with the last 18 in his role of director. He has also been a guest lecturer on the Virtual Design in Construction course at Unitec, and was interviewed as part of the development of that course when it commenced in its first iteration in 2016. This person's company already had a degree of cloud computing across their office work flow, and he was "confident that VDI is where we are heading." As did Interviewee 1, he thought the "ability to work remotely is seen as attractive." These discussions raised some interesting technical issues regarding network speeds, and the interviewee also stated that "licensing of software within VDI needs some clarity." Similar challeges to others were raised with the comment, "costs are seen as the main barrier."

Interviewee 5 is an IT specialist who has been working as a solutions architect at Unitec for over 21 years. Prior to that, he was a network engineer for a short period and holds VMware certifications. VMware is a proprietary cloud computing and virtualisation technology, and is used extensively in many VDI platform proposals. The magnitude of the decision to explore large-scale provision of VDI across Unitec was made clear when he stated: "Unitec is the first institution in the country to attempt this type of project and at this scale." This interviewee was the main point of contact for the author in discussing the proposed VDI provision, and also in setting up testing of different VDI configurations to see how Archicad performed and whether the end-user experience was acceptable. Initial tests on the VDI system just after its deployment was announced were very informal, and arranged at Unitec between the author and an IT technician employed to help with the VDI set-up and roll-out. The author's basic objective in these tests was to try and break the system while carrying out typical tests required of Archicad in the teaching labs. Development of the testing set-up progressed with the author and an IT colleague testing the performance of a single VDI computer using Archicad to perform typical tasks required of students taking the two papers under study. The rendering tasks required in Scoping and Preliminary Design were thought to be the most processor intensive, and the IT colleague downloaded a benchmarking tool to view the performance of the processors under load to note the particular characteristics of the software.

The load testing carried out later with multiple users was more sophisticated, and involved getting more detailed records of the time actually taken by VDI to complete specific operations. Users were logged in to the VDI system and provided with an Archicad project file of a medium-sized two-storey dwelling. They were then asked to carry out particular operations and tasks while recording the time taken to execute and complete, as a measure of the end-user experience and to compare outputs with a traditional desktop workstation.

Findings and discussion

INITIAL VDI SYSTEM DESIGN AND MANAGEMENT

All industry participants spoken to were highly aware of VDI, including cloud computing, and very conversant with the technology and how its potential could be applied to their core business. Participants echoed the literature in highlighting the flexibility of VDI and its ability to permit suites of software applications tailored to a company's needs. Some practices were already using cloud computing, to a degree, by use of the Autodesk BIM 360 package, with one stating that they used this system for 20% of their work but the rest was still done on workstations across a local area network. One participant stressed the importance of initial briefing discussions, and how firms typically sought to obtain satisfactory outcomes from VDI within their price points. He also felt there was a lack of knowledge and expertise amongst VDI vendors with regard to the specific requirements of the AEC industry, including an under-estimation of software demands on a system. In terms of overall VDI system management, the initial design of the framework was seen as critical, with approximate needs for a large office being some 24 users per server, whereas for a medium residential architectural practice 48 users per server was seen as sufficient. The system should be designed to be conservative, with some redundancy built in, and never operate at its limit on full capacity. Managing an IT system and VDI framework to serve the AEC industry was seen as challenging, and the VDI vendor stated the triangle of factors for consideration was performance, price and density (i.e., processing cores of sufficient speed).

The heat and noise from these installations also pose problems, with fans creating sounds likened by one participant to a jet engine. Heat, in particular, causes thermal throttling, degrading system performance, and therefore decisions taken regarding such factors at these early briefing and design stages are crucial. Software-specific requirements should not be overlooked, and these amount to more than just the possible licensing issues referred to in some literature (Kleppe & Bjelland, 2022). Licensing challenges are not seen as significant, but specific demands on the VDI made by applications such as Archicad or Revit should be investigated, including how the software behaves when executing complex tasks such as photo-rendering realistic three-dimensional views. Having multiple processing cores will be of little use if the software does not pass on the task-processing load from the first core, which may have to be specified at a higher speed. Memory management in a VDI system was another item arising in discussions, with dynamic-memory management being a feature possible in some VDI systems. Industry stakeholders were also concerned that the system should be scalable, to account for possible future expansion of practice workload, and this aspect of flexibility concurred with literature.

The initial VDI platform at Unitec was provided by an external cloud third party 'as a service', using a VMware multi-tenant solution. After conducting initial tests, however, and specifically around higher graphics requirements, this solution was deemed to be unfit for purpose. As a result, a custom vSphere single-tenant solution was built for the organisation that included Nvidia GRID technology to address the high-end graphics software processes. Grid technology at this juncture was not supported in a multi-tenant solution. This solution ran for several years, but various factors including periodic performance issues and a change in the organisation's direction led to an Azure desktop solution being adopted. This offered multiple options around high-end graphics requirements, better cost-saving opportunities and the ability to vary provision up or down as required. There was also increased system visibility, which enabled better capacity planning to quickly identify and thus rectify any performance issues that arose. This had been very difficult in the earlier VDI set-up as it depended on the vendor, whose suppled VDI solution to Unitec was subject to an intellectual property statement and therefore hidden from Unitec IT staff. This highlights one advantage of the move to the Azure virtual desktop, as the solution is now managed end-to-end by Unitec's IT department.

COST FACTORS AND VDI

Industry participants and the Unitec IT staff all stressed how important a consideration fiscal factors were in any decision. Cost–benefit analysis deliberations should also include server locations, and whether there should be one central server or a series in different locations. Some architectural practices involved in this study were at very advanced stages, in terms of comparing the benefits of a VDI system approach as opposed to traditional workstations. Identifying the costs of upgrading ageing hardware as opposed to investment in a VDI system was a fundamental objective, and separate cost considerations included a quotation from one VDI vendor of NZ$30,000 for a virtual license alone. A typical overall figure to cover 24 machines was estimated at NZ$43,000 for a VM license, to which would be added some NZ$85,000 to cover the Windows operating system license. The costs of procuring the architectural software for use in the VDI were additional, so final figures are significant; high licensing costs were identified by participants as potential barriers to VDI implementation.

REDUCTION IN UNDERUTILISED DESKTOP WORKSTATIONS

This was not highlighted as a significant issue by industry in comparison with the underutilisation observed within Unitec, which the institute's proposed VDI was deployed in part to help mitigate. One practice stated they had a 95% utilisation rate, with some 99% of their processing tasks carried out at individual desks. Such consistent utilisation figures may be unlikely across typical office hours over the long term in education, due to the nature of the business. However, there could be spikes at certain points in the academic year when assignments are due, and students may be accessing the VDI system across extended hours and at weekends, which, when measured across a set period, may compare with the industry figures. Despite this, reducing the perceived underemployment of computers and optimising the use of hardware through VDI was a major driver behind Unitec's decision to deploy.

IMPROVED MOBILE AND REMOTE ACCESS

This was seen as a significant benefit of VDI by the large majority of participants, both Unitec IT staff and practising architects. Unitec seeks to permit student access to IT facilities and software from not just within the classroom but from other locations throughout the campus, such as the library or wherever computing facilities are provided. The VDI system will recognise from the student's login credentials the qualification in which they are enrolled, and then allocate to them access to software appropriate to their courses, e.g., Archicad and Revit for relevant NZDAT papers. This VDI feature echoes a participant's recognition of VDI's ability to provide suites of applications tailored to a company's specific needs. The remote-access functionality is highlighted in the literature and by participants, who were all keen to enable staff to work from home, with one practice hoping to eventually facilitate 25% of their staff doing so in the future.

END-USER EXPERIENCE

This was mentioned by a number of participants and identified by Unitec as something they sought to provide to a standard at least comparable to that experienced when working on a traditional workstation. It was noted that this could be impacted significantly by the internet speeds available to the VDI platform, and also the effect of things like bandwidth potentially causing latency and a negative user-experience. These factors mirror the points made in the literature in relation to network and system health, and their effect on end-user experience and overall quality of service. An important point was made by the VDI vendor in relation to the significant difference in frameper-second rendering speeds possible in VDI when compared to traditional workstations. Virtual machines can render at 60 frames per second as opposed to the 144 frames per second attainable on a high-end workstation. This disparity could reduce with future improvements in VDI technology, but it may currently present an important consideration for some practices, and indeed education, if latency observed during complex operations in studio labs leads to frustrated students. This aligns with literature stating that if VDI is cumbersome in use and does not measure up to traditional workstation performance expectations, then users will find it difficult to accept.

TESTING METHODS AND VDI MONITORING

Unitec monitor the performance of their central VDI server and there is a member of IT staff with a responsibility for quality of end-user experience, but certainly lecturers in the School of Building Construction had not been aware of any specific notification and recording process differing from the generic incident-reporting process. There has been some testing set up to monitor the performance of Solidworks in the VDI environment, but nothing was identified in discussions regarding other applications, such as Archicad or Revit. There is, however, a VDI trialling report provided to the author that showed a very structured framework of tests for various applications on VDI, such as Skype for Business, and including use of peripherals such as headsets. This report also identifies tests done using Archicad involving operations such as opening a sample file and paraline views, which were also opened in 3D for rendering. This test noted crashes when rendering a 3D view and also when publishing drawings, but occurrence depended on the graphics processing unit set-up with, interestingly, the GPU Power set-up with 8GB of RAM, as opposed to the 4GB of the GPU Pro, having more issues. The Power and Pro set-ups were identical apart from the RAM provision.

Initial testing instigated by the author upon being notified of the imminent deployment of the VDI at Unitec was to meet up with an IT colleague and run Archicad across the platform on a terminal in the institute’s library. This simple test took place in August 2017 and involved opening up an Archicad file of a two-storey dwelling. This test ran very smoothly, with what the author considers impressive results, up until an attempt was made to render a 3D view. As in the official test referred to above, the machine crashed. Another operation that caused a crash was an attempt to export a file to the IFC (Industry Foundation Class) format. Subsequent dialogue with the local Archicad software vendor confirmed that they had also encountered the exact same two problems when trying to run Archicad using VMware, although they did not state whether they had discovered a way to resolve it. Further discussions with the software developer Graphisoft revealed that they did not support application virtualisation at this juncture.

Based on the feedback from this initial test, changes were made to the VDI set-up that resolved the two main problems identified. Both the rendering and IFC export functions of Archicad are made possible by additional plug-ins to the main application, and this knowledge enabled the Unitec IT staff to revise the platform to prevent the crash problem observed earlier when exporting to IFC.

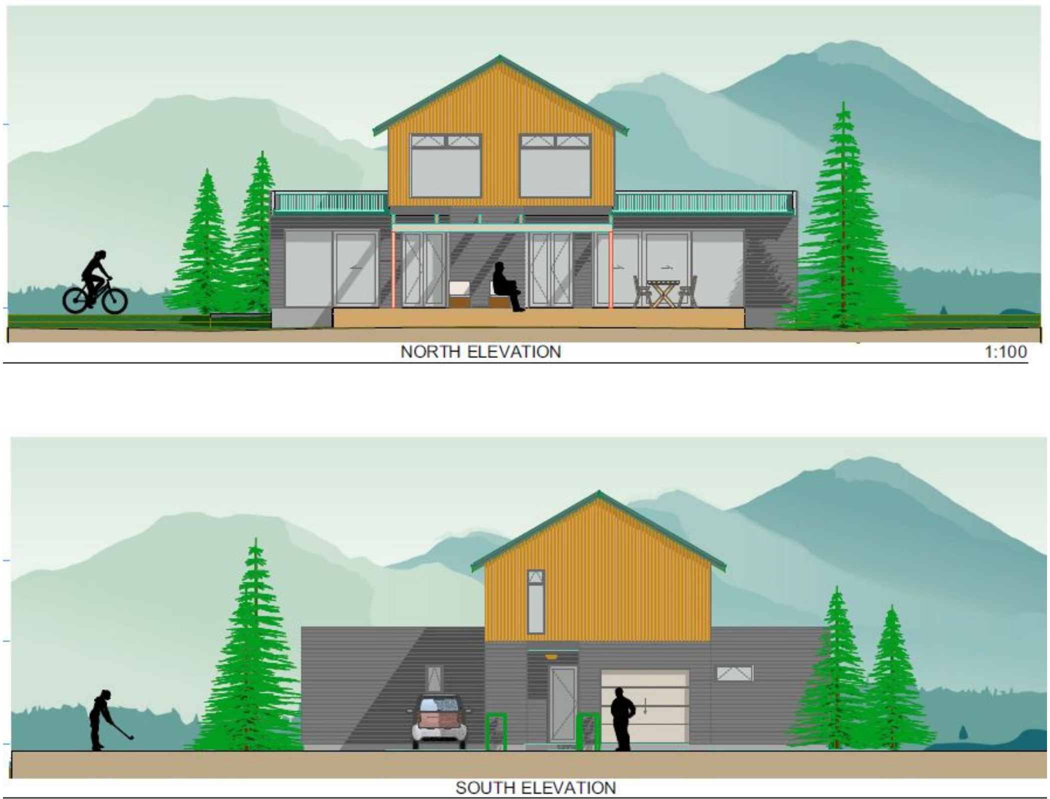

Figure 1. Typical design elevation drawing produced by students showing trees, plants, sky, shadows and people. Image: Emma Zhu.

A similar test was carried out in April 2019 to again try to ascertain in more detail how Archicad would perform when executing complex tasks across the VDI. The programme had been utilised fairly successfully when teaching one course in previous semesters and, though no crashes had been recorded, a noticeable degradation of performance had been observed when groups of students tried to render 3D images simultaneously. This individual test was carried out by the author and the VDI project manager at Unitec. An Archicad dwelling file was again opened up and tested by opening various views, but this time the performance of both the CPU and the GPU were monitored via a utility downloaded by the IT colleague from the internet. In this test, the software performed the requested tasks and no significant lag or latency was observed. The main observation from this test, however, was that Archicad was more dependent on the CPU to execute tasks such as rendering, with this component operating at close to 100% while the GPU was not working at anything near the same level. A follow-up test to compare the time taken to complete operations was done using two Windows machines of similar specifications and also using an Apple MacBook Pro laptop. The specifications for the machines used in the follow-up test are given in the table below.

TABLE 1. TESTING RESULTS ON ARCHICAD SIMPLE RESIDENTIAL MODEL FILE OF SIZE 57.7MB.

Computer and operating system	CPU	RAM	GPU	External rendering time	Internal rendering time	Elevations layout rendering time	Sections layout rendering time	Time to load file
UNL 103268. Lab 114-1003. Windows 10 Enterprise 2017. 64 bit	Intel Xeon® CPU E5-1603® v3 @ 2.8GHz	16GB	Nvidia Quadro K2200	16 mins 53 secs	1 min 58 secs	10 seconds	11 seconds	1 minute
UNL106198. Office computer. SSD Windows 10 Enterprise 2015. 64 bit	Intel® Core™ i5-6500 @3.2GHZ	8GB	Intel R HD Graphics 530	14 mins 40 secs	2 mins 8 secs	13 seconds	8 seconds	40 seconds
Apple MacBook pro. Mojave OSX 10.14.4	Intel i7 2.2GHz	16GB	Intel Iris Pro 1536 MB	10 mins 39 secs	1 min 12 secs	6 seconds	8 seconds	1 min 9 secs
VDI computer run in lab 114-2009	Intel Xeon® CPU E5-2698® v4 @ 2.2GHz	8GB	Nvidia Grid M10-1B	18 mins 35 secs	2 mins 30 secs	17 seconds	12 seconds	2 mins 17 secs
Multiple (19) VDI computers run in lab 114-2009	Intel Xeon® CPU E5-2698® v4 @ 2.2GHz	8GB	Nvidia Grid M10-1B	Typical time 3–3.5 mins but times of 9.41, 16.55 and 21 minutes noted.	Typically 3–4.5 mins but times of some 21 and 23 mins noted	Not recorded but no lag observed	Not recorded but no lag observed	3 minutes

The VDI system when testing only one machine was generally slightly slower to perform the tasks, but the amount of RAM allocated to the VM at the time of the test could be a factor here, in addition to the actual VDI platform itself.

The final test set-up was a load test, whereby the tasks described above would again be carried out across the VDI system but this time on some 20 machines simultaneously. This test was devised to try to replicate a typical studio class with students employing Archicad to model up two-storey Major Project house assignments.

Temporary login codes were obtained, and the author and three colleagues logged in to the VMs, loaded up the same Archicad file and commenced executing a set list of tasks. Participants were asked to note the performance of the computer during these operations and note any irregular behaviour such as latency, crashes or unreasonable durations taken to complete tasks such as rendering. For the renderings, each participant was given the same settings for this particular operation, e.g., resolution, final image size and lamp parameters, although in practice students would be expected to experiment with these and individual selections could impact on time taken to complete a render. Despite this expected real-life variation, however, it was felt that using the same files and settings would not impact significantly in establishing how the VDI system coped with multiple simultaneous users. Using the temporary log-in credentials to access the VDI, all four participants proceeded to copy the Archicad project file onto the computer desktops. When this was completed, participants were given a briefing and instruction sheets listing the tasks to be executed. It was noted immediately that the typical way of opening the Archicad software by double clicking on the file did not work on most of the machines. Participants instead had to right click and choose the Archicad component identified by the computer to open the file, which took slightly longer than usual, with opening times being around three minutes. This could be down to the VDI system having to identify the new user login profiles, allocate the correct software suite and then open the file with the correct application. This delay in opening files has also been identified by students using Archicad on the VDI in recent semesters.

When all projects had been opened by the participants, who each monitored and operated four or five computers, plan-section and elevation views were opened up and operations such as pan and zoom attempted. The system performed well in these tasks and no latency was observed, with behaviour equating to that experienced on a workstation with a local software install. The only slight delay noted was in elevation views that contained 3D objects such as trees, but the initial generation of the view was well within acceptable time limits.

Participants then set up 3D views for photo rendering, a task that requires a lot of processing and can typically make a computer work hard and for extended periods, depending on the settings assigned to the photo render, such as image size, resolution, etc. The initial renders were assigned parameters in the rendering package of low quality, to get some idea of how long the operations would take, as it was believed by the author that simultaneous rendering on the VDI could be time consuming.

Figure 2. Typical cut-away plan view showing house ground floor and various 3D objects to be photo rendered. Image: A. Jensen.

The rendering operations were commenced as simultaneously as possible, with one participant to five machines, and the time taken to complete the operations was recorded by Archicad and noted by the author. Exterior renderings generally took some 3–3.5 minutes, but there were some of over 9 and 16 minutes recorded, with one machine taking some 21 minutes to complete the render. Similar results were observed when producing the interior photo renders. Most machines completed acceptable images in 3–4 minutes, which all participants agreed compared well with traditional workstations. Some outliers were noted here also, with some machines taking over 20 minutes to complete images. These images involved settings where Archicad lamp objects were assigned to provide indoor light sources, and this seemed to slow the operation down compared to an image where the only light source was the basic default Archicad sun object lighting the scene.

The rendering settings were adjusted to high quality on some machines, to check effects, and one machine registered a memory warning, with a subsequent freeze, trying to render an A4 image at 500 dpi.

Rendering 3D cutaway section and plan views using basic outdoor daylight settings presented no problems at all, and operations were typically completed in just over 2 minutes.

The overall view of all participants, based on their observations in this test, was that the VDI system performed well and compared favourably with their own experiences in executing similar tasks on traditional workstations.

A few days after this test was completed, a class was taken by the author in the same room and students had to generate rendered images for inclusion in a drawing set assignment due for submission in the coming days. Of the class of 22, some five students were using their own laptops with the approximately 17 remaining working across the VDI. The VDI system seemed to cope well with the drawing demands made of it until the latter stages of the class, when a number of students encountered issues. Five students noted system crashes, in which an error message occurred just before a total crash, which required a restart.

Although vSphere provides some great insights, being offered 'as a service' meant the organisation's ability to access this information was limited. At that time, getting specific insights to graphical resources usage was only available at the host console access, and was outside the reach of Unitec IT staff. In addition, at one point, certain patch and firmware upgrades completely broke this already limited console-level visibility and left parties, as one IT colleague states, "flying in the dark."

Due to the lack of live and historical information at platform level, Unitec IT staff, through controlled tests, leveraged performance tools at the VM level. Performance monitoring in conjunction with use of GPU-Z during a simulated typical workload session provided valuable information. These tests, replicating typical tasks carried out by students in class, conclusively proved that the provisioned resources at that time were inadequate for the graphically intense workloads required on some occasions. These findings and discussions with teaching staff led to a new revised VDI provision being put in place for further testing and monitoring during in-class use.

PERCEIVED BENEFITS OF VDI

The benefits highlighted by the Unitec VDI project staff, both in discussions and in their VDI trialling document, include cost savings of approximately NZ$1 million across some 500 computers over a six-year period. Also noted were the sustainability aspects of VDI, with power consumption approximately 14% of that of a PC. The other main drivers for deployment were the potential to increase computer utilisation by removing the reliance on classroom attendance, and the potential for students and staff to work remotely using the VDI system in the future. VDI systems being scalable, and with flexibility features such as dynamic memory management, were also seen as being of value.

Participants from architecture firms interviewed all agreed that VDI is where we are heading, in terms of how software is provided to users, and their companies were seriously considering its implementation. They also wanted to know about factors such as scalability and flexibility of the VDI platforms available, as these were also seen as valuable features in helping them to future proof their software provision to their staff.

Automation is seen as one of the primary ways to cut costs when deploying VMs. Unitec's initial solution design attempted to factor in the nature of the organisation and the fact that for several months in a typical year, there would be no students requiring access to machines. The organisation has considered learning oportunities beyond a typical Monday to Friday, 9 to 5 window, and instead planned for an improved access provision with labs open and available at weekends and 'drop-in' times, potentially leading to future 24-hour availability. The original platform had the ability to shut down machines and power up as needed, but having learners wait several minutes for a desktop to become available was deemed an unacceptable end-user experience.

The new Azure platform is based on a 'pay as you go' model, where machines are shut down automatically during quiet periods. In a typical morning, more resources are spun up and the platform will automatically bring up new instances within just a few minutes of a new user session being initiated. Unitec's organisation aims to have at least 20 virtual sessions available at any time during typical business hours, in an effort to avoid users having to wait too long for a virtual desktop to become available.

Under Azure, the organisation is not charged when CPU and memory are not being used, but there is a continuous charge for storage. As these machines use premium storage, this is one of the more costly aspects of this VDI solution. However, by using a management product called Nerdio, as machines are shut down the storage disks are automatically converted from premium to low-slow mechanical storage to help keep running-costs down. The only disadvantage of this approach is that it can have consequences on the period required for a desktop to be available to end users and this can apparently vary. Unitec's organisation has opted for retaining the premium storage capacity, which is converted to a low-cost option when machines shut down. As machines are powered up, the storage is automatically converted back to premium in an attempt to ensure maximum performance and a better end-user experience.

Achieving the above is possible without using Nerdio, but the product brings several other features that augment the VDI platform's native abilities, thereby helping to reduce overall system management and leading to considerable savings.

If an organisation contracts in to using Azure for a number of years, there are possibilities for further discounts. However, this would need some certainty from an organisation in terms of how many VDI instances they may actually require in the future, to gauge whether such a commitment is of any real fiscal advantage. Increased monitoring of VDI systems over time and making use of the better telemetry information systems now available will enable more informed future decisions to be made regarding such additional cost benefits.

CONCLUSION AND RECOMMENDATIONS

Virtual desktop infrastructure has the potential to provide benefits to many user groups, including educational providers and businesses. System security and management, cost savings, flexibility of software provision and remote platform access are some of the main benefits identified in this research. Barriers are present, however, and items such as capital expenditure and running costs do present challenges for industry, where fees for VMs, and numerous licenses covering operating systems and required business software, can soon become items of substantial consideration.

To ensure any VDI system is fit for purpose it is vital that clients articulate their objectives clearly to potential vendors, as in any briefing process. The education institute or AEC company should identify the software required to be provided on the VDI system and highlight the outputs necessary, whether for student assignments or the core business of, for example, an architectural practice. These outputs should be analysed to determine which may provide the most demanding processing loads on both the software and VDI platform. Such tasks can include production of colour photo renderings on Archicad, but other applications such as Revit may work in different ways, with different tasks generating peaks with potential for crashes. It is therefore imperative to discuss with the software provider the way the programme operates in terms of whether it draws from a CPU or GPU when executing particular tasks. Archicad, in recent versions, utilises a multi-threaded approach, in which it employs different CPU cores, permitting various operations to be carried out simultaneously with some happening in the background. It does, however, still rely very heavily on the first core for certain operations, and this type of application-specific information will be invaluable for potential VDI vendors to ensure their system proposal is fit for purpose.

Confirmation should also be sought stating whether any additional bolt-on software is required by the basic application. Archicad, for example, often installs and uses a bolt-on rendering engine for enhanced 3D work, and another plug-in facilitates export of file types such as IFC. These plug-ins posed problems with Unitec's initial VDI set-up, but the problem was resolved once identified.

Flexibility of the final VDI system is important to industry and academia. Software can often be updated, including interim patches, and it should be made clear during initial VDI briefing discussions what costs, if any, to the client could be incurred by modifications to the VDI platform. It should also be determined whether the VDI system allows changes to how the CPU cores work to make optimum use of software such as Archicad, as discussed above, and other sophisticated packages. Memory management should also form part of these discussions, and whether temporary changes can be made to cope with anticipated periods of high demand, such as at the end of a semester when assessment submissions are due. Workload demand on the VDI processors and graphics cards will not be as constant in a teaching institution as it is in a typical architectural practice, so a feature permitting resources to be allocated at specific times to meet peak demands should be considered.

Industry has highlighted the need for the VDI proposed by a vendor to be scalable, permitting increased users and groups to address expansions in practice staff during times of high workload. This feature was emphasised in discussions with the researcher during the study. Academia should also consider this future-proofing aspect regarding their software provision. Dialogue on these aspects should address the allocation of the CPU in terms of how many users will share its resources, e.g., 4, 8 or 16 users, and whether these figures can be modified.

Briefing discussions, whether within industry or academia, should take place with a credible point of contact within the relevant organisation. If information is provided by someone unfamiliar with the required software outputs for a particular course or company, then this incomplete data will risk the final VDI proposal being unfit for purpose.

It is strongly recommended to test the VDI system before deployment to ensure that it has the capacity to achieve the required outputs of the company or institute and across a range of potential scenarios. Machines crashing on the day large groups of students are due to make important assessment submissions will lead to much frustration and stress, and will certainly be echoed in similar industry scenarios.

VDI has much to offer to both academia and business, but if the fundamentals are not put in place following detailed and comprehensive briefing discussions, acceptance and promotion of this exciting new approach will be difficult.

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