Creating a Smart Visitor Management System

OXFORD
BROOKES
UNIVERSITY

BLENHEIM PALACE

Executive summary

Built over 300 years ago, Blenheim Palace is the premier visitor attraction in West Oxfordshire and a UNESCO World Heritage Site. Each year, nearly a million people attend its events, explore its gardens, or marvel at its Baroque architecture and lavish state rooms. It is also a crucible of innovation and experimentation, not least for digital data and advanced information technology.

This booklet tells the story of recent collaborative work at Blenheim involving Oxford Brookes University. It explains the background to this effort and how it led to a Government-funded Knowledge Transfer Partnership (KTP). It is intended for anyone working in or for a UK visitor attraction who is keen to learn from Blenheim's experiences and wants to replicate some of its successes.

At the heart of the KTP was a vision for a Smart Visitor Management System (VMS) – an integrated, forward-looking digital platform that harnesses the range of data sources available across the palace. Rather than simply recording and reporting on past events and transactions, the VMS is smart in two key ways. First, it draws upon real-time data, much of it from some 200 sensors, many installed during the partnership itself. Secondly, the VMS then applies machine learning algorithms, to provide accurate predictions of visitor numbers and the likely movement of people across the estate.

The pages below cover the range of issues the project team faced in creating an infrastructure for capturing, storing and analysing palace data, and making this available to a range of users via different interfaces and access devices. If you're interested in being part of this journey, there are details below on how to get involved.

Foreword

Dominic Hare
Chief Executive
Blenheim Palace

At Blenheim, innovation and data are at the heart of our mission to preserve and protect this extraordinary estate for future generations. As we embrace the digital age, leveraging advanced technology has become vital to our operations. Our smart visitor management system is a key example of this, allowing us to understand visitor behaviours in real-time, optimise crowd flow, and enhance the overall guest experience. By harnessing data-driven insights, we can better protect our heritage, manage resources more efficiently, and deliver personalised experiences that set us apart. This approach not only strengthens our visitor strategy but also provides a crucial competitive edge in an increasingly dynamic tourism landscape.

Contents

4

5

Data, Data, Everywhere

For over a decade, digital data has grown exponentially at Blenheim. This has included transactional data from shops and catering outlets, financial data, and customer data from event bookings and annual passes. In more recent times, sensors and WiFi have increased the rate at which data is generated and captured.

While data is undoubtedly viewed as an asset, the challenge has been to pull this all together to support better decision-making. In 2014, the palace created its first real-time reporting platform. While a leap forward, this still suffered from a lack of standardisation in measurements (e.g. for weather) and was mostly backward-looking.

The next phase of digital innovation therefore had to involve a deeper integration of data sources and provide better ways of contextualising what information there was. It also needed to be more future-focused and allow for real-time monitoring. Added to this, the palace wanted to see how things were connected across its areas of activity, particularly the way visitor numbers and experiences were impacted by marketing initiatives and operational decisions.

"With insights from the system, we're able to predict visitor trends and deploy resources more effectively, from staffing to maintenance. It's allowed us to make smarter, faster decisions that directly enhance the visitor experience."

Heather Carter, Managing Director

What types of data do we have available?
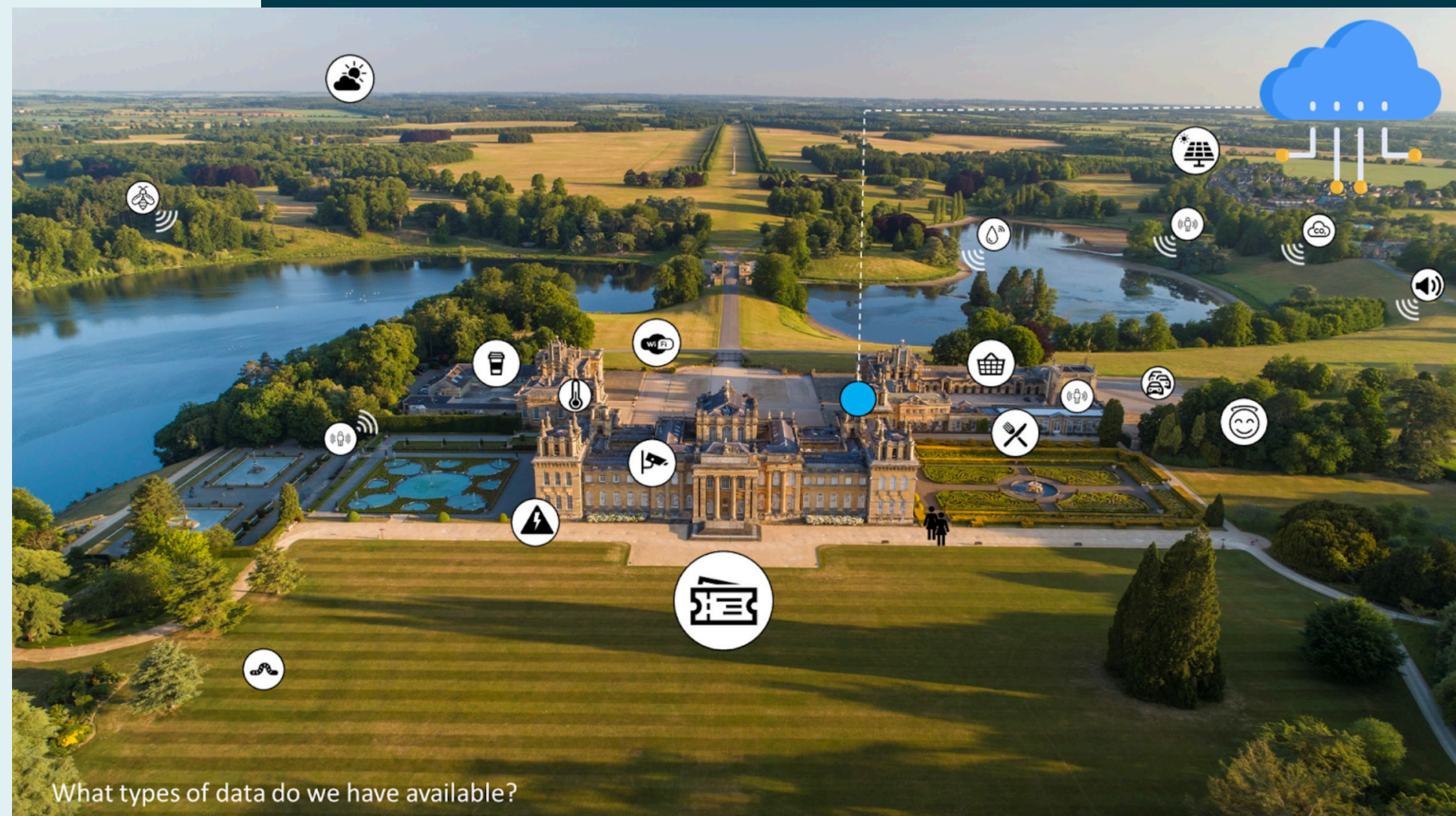
By 2019, Blenheim had a clear sense of where it wanted to go and, in some cases, what this might look like. Top of the list were management dashboards to support better decision-making, especially those promoting real-time understanding and insight.

## Target areas for development included:

- Revenue tracking
- Marketing effectiveness
- Visitor demographics
- Customer feedback analysis
- Strategic planning

There was also interest in the potential of new technologies, such as artificial intelligence (AI). Lacking experience and capacity in this area, Blenheim partnered with Oxford Brookes University, securing innovation funding via the Government's Knowledge Transfer Partnership scheme.

Knowledge Transfer Partnerships (KTPs)

With match funding from Innovate UK - the body that awards and oversees KTPs - Brookes and Blenheim embarked on a 32-month project.

Workplace supervisor

Recent (post) graduate

Company

Academic team

Associate

University
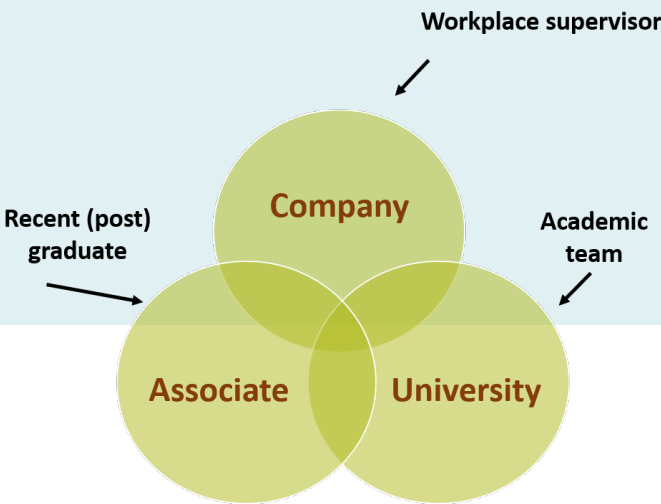
Like any KTP, at the heart of this work was the Associate. These are typically recent graduates, although Associates these days often have a Master's degree or even PhD. The Associate is supported by a workplace supervisor, in the Blenheim case, the Head of Innovation. He or she is also aided by the 'knowledge base team', academics drawn from the partnering university that meet regularly with the Associate, as well as with the wider team at the partner organisation. Governance of KTPs also includes input from an Innovate UK Adviser.

"This KTP is an excellent example of what can be achieved when you bring together a forward-thinking organisation, in this case Blenheim, and the deep expertise and academic rigour from Oxford Brookes University. The Smart Visitor Management System the team have jointly developed is already helping Blenheim work more efficiently while enhancing the experience of visitors to the Palace."

Dr Matt Hogan, KTP Adviser, Innovate UK

The vision for the partnership was formed in 2019 following a workshop with key stakeholders from both Blenheim and Brookes. This set out to answer several key questions, such as:

- What data (and data-driven insights) did the palace already have that would make a major difference if available in real-time?
- What data (and insights) were not yet to hand but would make a big difference?
- What data, while available, was particularly under-used? How might this change (e.g. better integration with other data, or real-time reporting)?

The results led to the notion of a Smart Visitor Management Systems (or Smart VMS), which would have two sets of components:

- A Customer Insight and Prediction system (CIP) and
- A Customer Experience and Flow system (CXF)

The CIP elements were intended to generate a better understanding of visitor characteristics and likely visitor numbers on a given day in the calendar.

The CXF parts, by contrast, were focused on real-time behaviour. These were aimed at helping staff to shape the visitor experience to the optimum, once on site, as well as aiding the efficient use of palace resources.
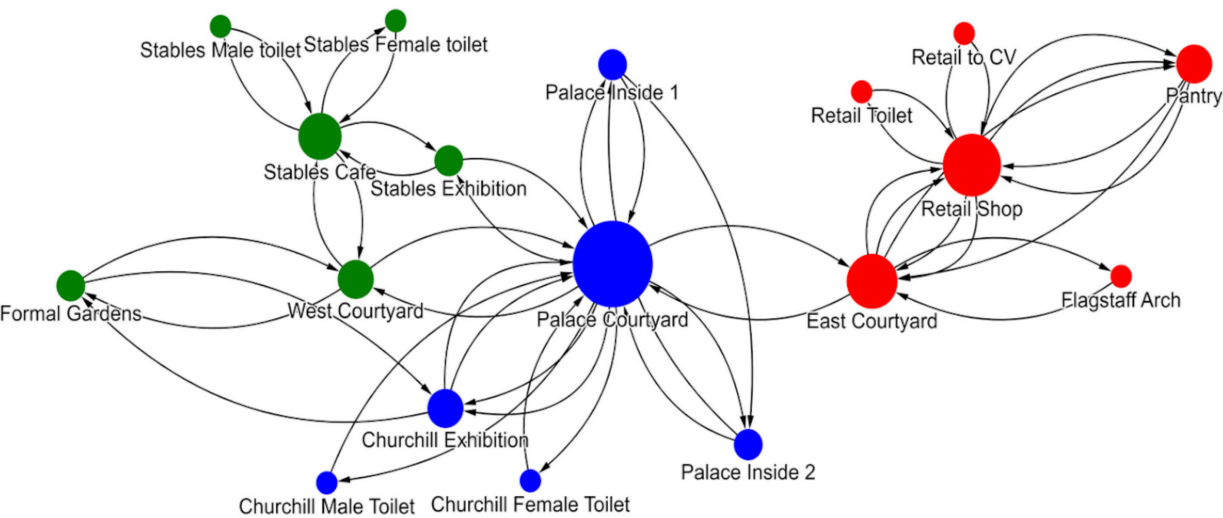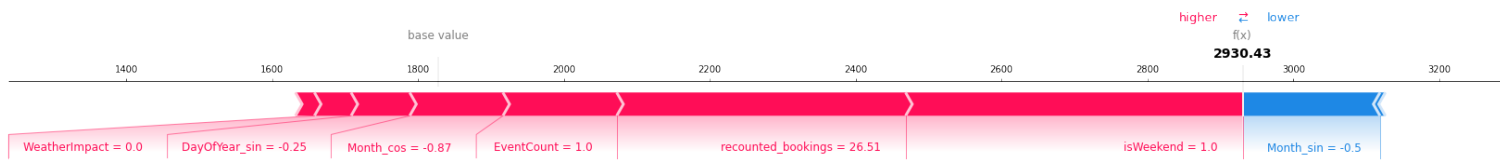
As mentioned above, Blenheim has seen continuous growth in digitised data. Some of this was the result of new data points that were created across the palace during the partnership with Brookes.

Two related steps were critical to this and involved (1) the installation of over 200 sensors, and (2) connecting these to a LoRaWAN network.

Sensors

Sensors come in many forms. As the diagram on page 7 shows, Blenheim can now collect data on environmental conditions both inside and outside palace buildings. As these operate using batteries with a life of between 2 and 5 years, there is plenty of flexibility as to where the sensors can go.

Externally, the sensors are used to record weather conditions, water levels and ambient noise. Inside the palace, data is now captured on temperature and humidity.

Of all the sensors now in position, perhaps the most revealing have been the bi-directional footfall sensors, which count the number of people moving around key parts of the estate - both inside and out (more on this later).

LoRaWAN network

To harness this data, a network was needed that could receive input from the sensors at regular intervals (typically every 5 to 15 minutes) and move it in packages to a central network server. To do this, Blenheim put in place a LoRaWAN network, a low-powered platform that can talk to devices up to 10km away (depending on geography and obstacles).

Taken together, the sensors and LoRaWAN are essential parts of the palace's IoT (Internet of Things) strategy. Without the need for 4G or WiFi, they enable the physical world, and the actions of people within and around it, to be measured, digitised and communicated, thus feeding the data capability needed for smart visitor management, as well as other things.

The Data Hub

As noted earlier, the new data points are connected via the LoRaWAN network to the network server. This 'Data Hub', built in Microsoft Azure (a cloud storage system) is also the repository for the various sources of financial, customer and other transactional data discussed earlier. The ability to analyse and present data across different datasets, looking for and exploiting patterns and insights, is another key part of the Smart VMS capability.

The Azure environment has allowed the team to work with best-in-class technologies and tools, not least the APIs (application programming interfaces) that allow systems to interchange data for integrated analysis and reporting. This also incorporates external inputs, such as weather and traffic data from Google.
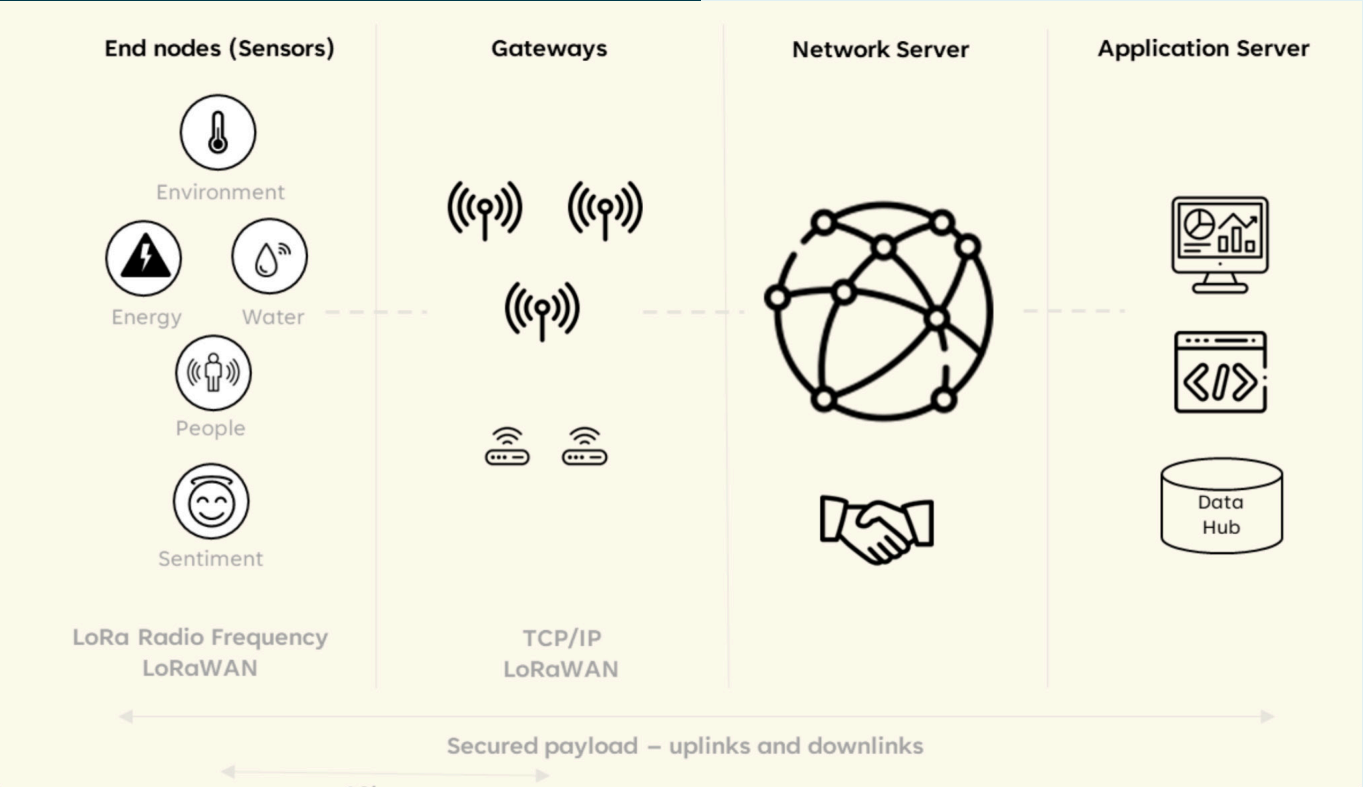
The Product Hierarchy

Of course, to make data accessible and open to interrogation, work is needed on the underlying data structures. Blenheim therefore created a 'product hierarchy' of data types (e.g. retail till data, cafe sales data), so that datasets are stored in a meaningful way with a clear sense of context in terms of how items relate to one another.

Adventures in Apps, Alerts and AI
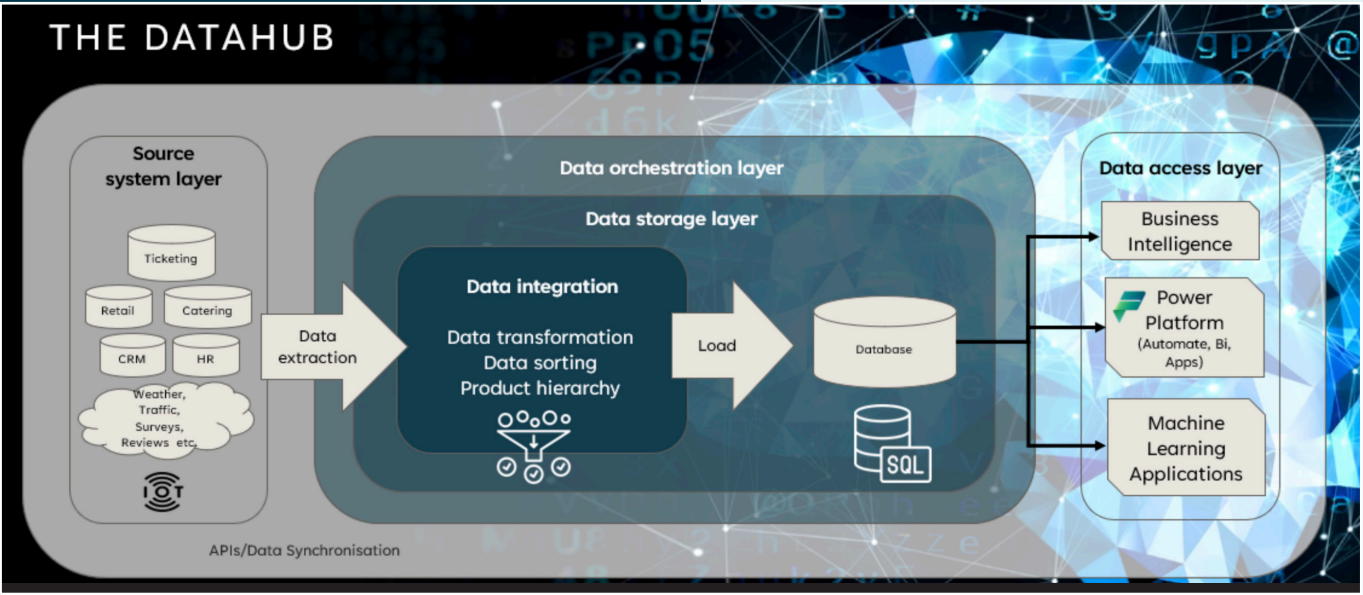
The KTP project was intended, in part, to explore the opportunities for AI-enabling Blenheim's digital systems. One business application came early in the partnership, thanks to challenges brought by the Covid pandemic.

## The 2020 Christmas Lights Trail

Covid hadn't helped with the KTP, delaying its start and then disrupting the regular pattern of visitor data. It also presented a problem during the 2020 Christmas lights trail, where there was a duty on the palace to manage visitor numbers to avoid bunching of people in any one area. With over 4,000 visitors per night during the season, this was a matter of some urgency.

By placing footfall sensors across the 2.9 km of the trail, it was possible to monitor numbers in real-time. However, this was not as simple as counting the people passing a sensor and just totalling the results. Sensors can get knocked and misaligned; they sometimes miss people, particularly when they're walking in parallel. The noise caused by omissions and errors is not unusual in any digital system, however, and was an early area where AI-related technology could be used.

In the case of the lights trail, a mathematical filter was applied, which looked at the sensor and flow data in a 'probabilistic' way. This produced a more accurate representation of what was actually going on, allowing for the numbers to be evened out and more reliable judgements made in managing operations.

Error Distribution: AI vs Budget Predictions (Jul-Sept 2024)
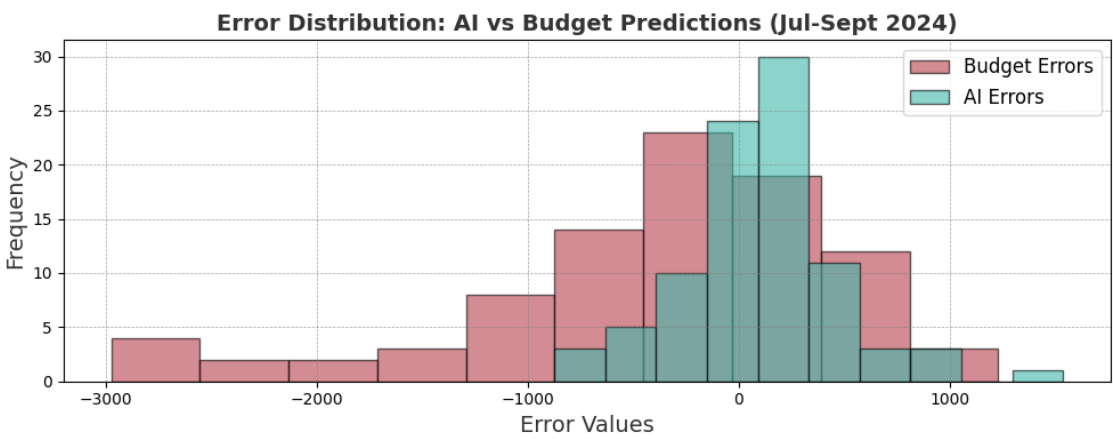
AI vs Budget: Prediction Performance Overview (Jul-Sept 2024)
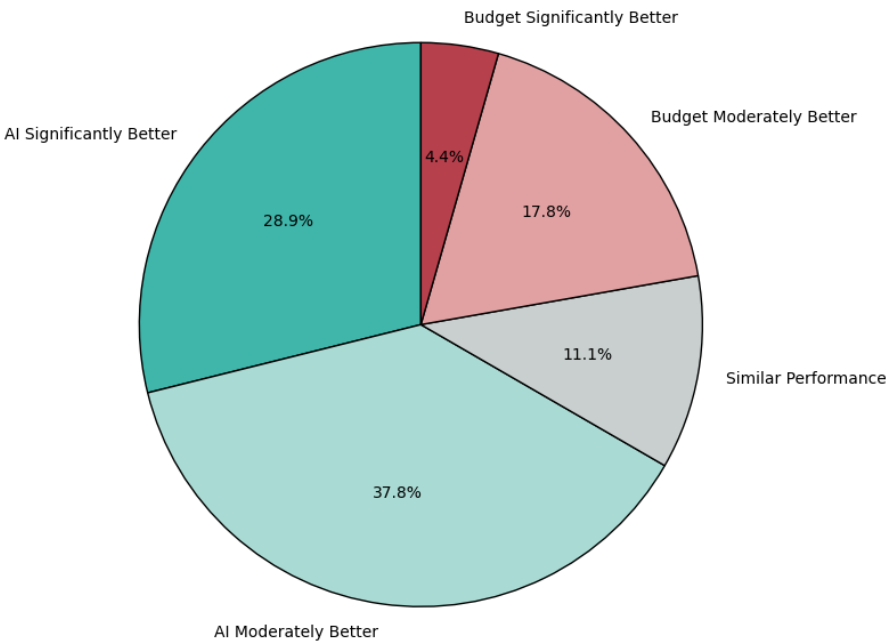
Other AI models

Since the start of the partnership in the summer of 2020, to the present post-KTP phase of the work, a range of models have been tried and tested as part of Smart VMS developments. All these are 'containerised' within the Azure cloud storage. Most are machine learning algorithms, clearly falling into the AI camp. Others are typically found in the mix of tools a developer would use in addressing data modelling and prediction exercises. For example, solutions at Blenheim have included:

- Multiple Linear Regression (which looks for linear relationships between variables)
- Gradient Boosting (which combine several analyses to produce more accurate predictions)
- Neural Networks (which, like the brain, learn by making connections between nodal points in a data structure)

The 'Similar Day' Algorithm

One of the key innovations to come from the Brookes-Blenheim partnership has been the 'Similar Day' algorithm. This has built on the years of data generation, integration and curation, and the training of a range of machine learning models.

The algorithm works by taking each day as a snapshot and looking at past days that were most similar. Key variables here include: days of the week, times of the year, advance bookings and forecasted weather conditions.

Initially, the algorithm also included the palace 'budget' for a given day - the forecast (and effective target) for visitor numbers and income on the date in question. However, after much refining and testing, the algorithm proved more robust with the budget taken out as a variable. It now outperforms the budget as a predictor of visitor numbers by a significant amount, as shown on page 15.
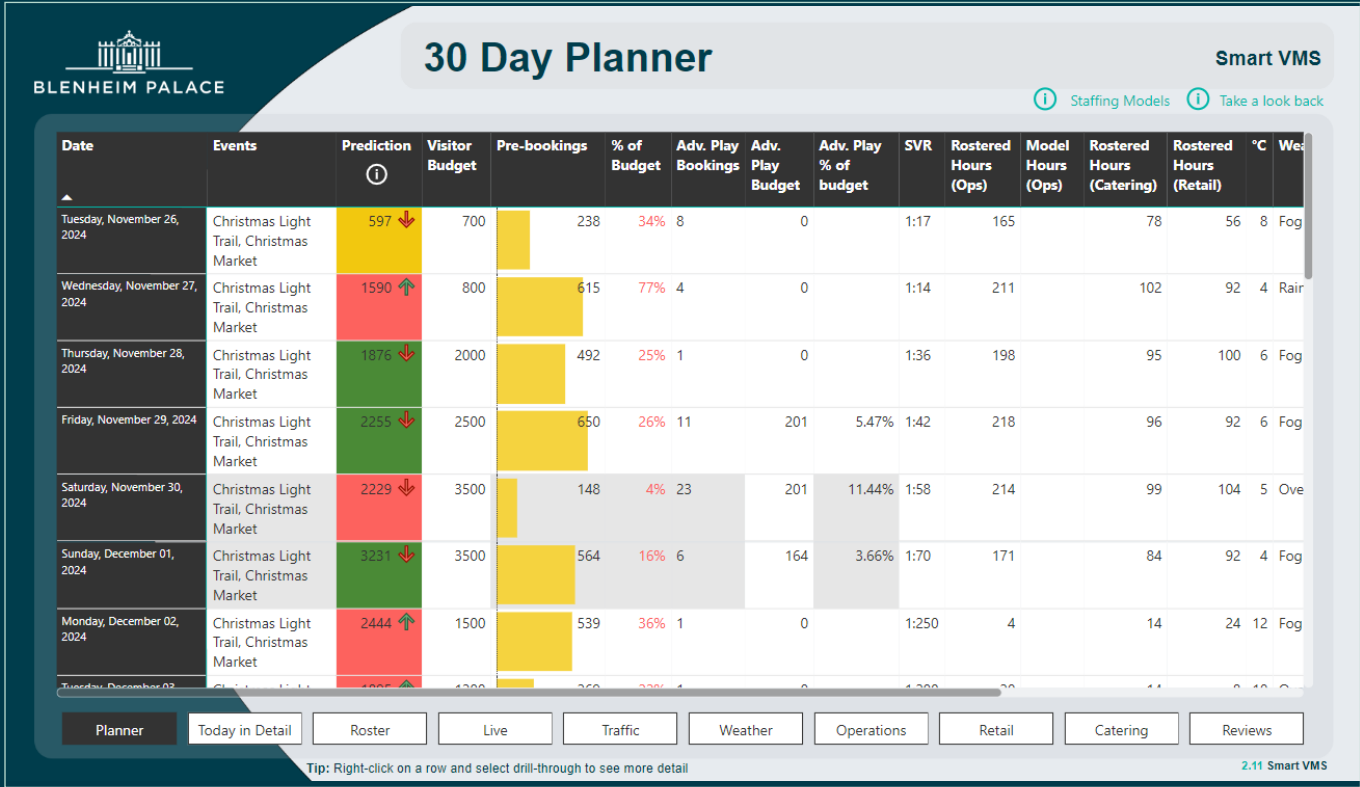
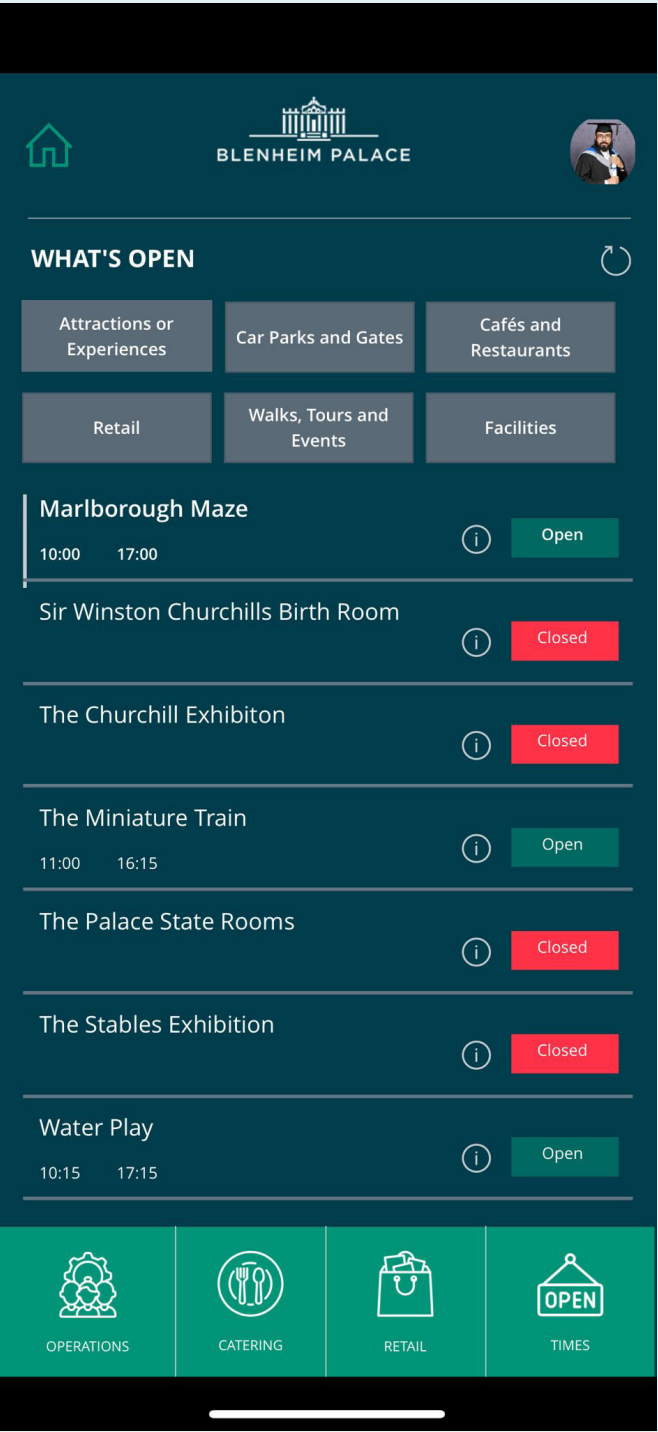
Alerts: using real-time data to drive decision-making

The Visitor Experience and Flow part of the Smart VMS was envisaged as a way of generating live insights into events on the ground. The holy grail, of course, was to anticipate developments (typically surges in demand) and prepare for them ahead of time.

Doing this accurately is one thing, getting it in the hands of users in a form they can work with is another. The solution, in a number of cases, came in the form of alerts. From footfall sensors near toilets flagging up the need for cleaning, to ANPR cameras used to identify coach arrivals, the alerts are literally putting information in the hands of users, not least via the project's smartphone app.

PowerApps and the Empowered User

The apps were built using the Microsoft PowerBI Platform, allowing for a 'low-code' approach to application development. These are fed by the same data and algorithms as desk-top systems, but are designed for mobile users.

The app includes a WOW - What's Open When - function, that provides staff with real-time details of which parts of the palace estate are currently open or closed (exhibitions, catering outlets and other site facilities will open and close at different times, for example). This allows users to direct visitors and staff resources to best effect.

Dashboards, displays and ambient intelligence

While management dashboards have come into vogue in recent years, they are not a fad that is going away. Graphs, tables and pie charts provide powerful visual aids when interpreting complex information and judging its significance. It was for good reason then that the Brookes-Blenheim work had a line of sight to dashboard development from the off.

PowerBI Powered by the Hub

Without all the work on generating, integrating and curating Blenheim's digital assets, new interfaces and access channels would be of little value. With the help of AI models and other forms of statistical analysis, greater insight was being created from this data. But for it to add value to both staff and visitors alike, insights and predictions needed to be acted upon. Better interfaces, more appropriate channels and more timely messaging were all key to this.

One crucial technology here was PowerBI, Microsoft's visualisation software, which provides a potent means of presenting data in a user-friendly way. (Of course, there is other visualisation software out there, which may be more suitable to other visitor attractions, depending on their IT systems.)

Not to be missed: Wall-mounted screens of data

For most staff members, particularly office-based ones, desk-top screens are the main means through which they access data and dashboards. But a systematic attempt was also made to install wall-mounted displays across staff areas, so that the same information was available through a series of rolling screens.

Taken together with the app - which provided mobile support on hand-held devices - what emerged here was a form of 'ambient intelligence': wherever people were across the estate, predictions, analyses and alerts were available to them (and, at times, were hard to miss!). For Blenheim, this also helped with the long-term plan of developing a 'data culture' at the palace, raising awareness of the information systems available to staff and the importance of making decisions in a data-driven way.

As the story above might suggest, 2024 has proved to be a year of optimisation and exploitation for the Brookes-Blenheim collaboration. It has been a chance to fine-tune algorithms, promote the benefits of more accurate forecasting, and to put this in the hands of users via easy-to-use tools and information systems.

It has also been a stage where new opportunities can be exploited, building on the emerging digital capabilities. One recent example has been the use of Microsoft's Power Automate. This is essentially workflow technology that orchestrates and mechanises regular tasks, exploiting the data assets and analytical insights.

At 6am, for instance, staff can now receive a snapshot for the coming day, providing, among other things, predictions of visitor number, vehicles, and sales, and expected peaks in demand.

At the end of the afternoon, there is also now a 'daily digest', summarising the day's results. This involves scraping customer sentiment from relevant social media platforms and making it available in one paragraph.
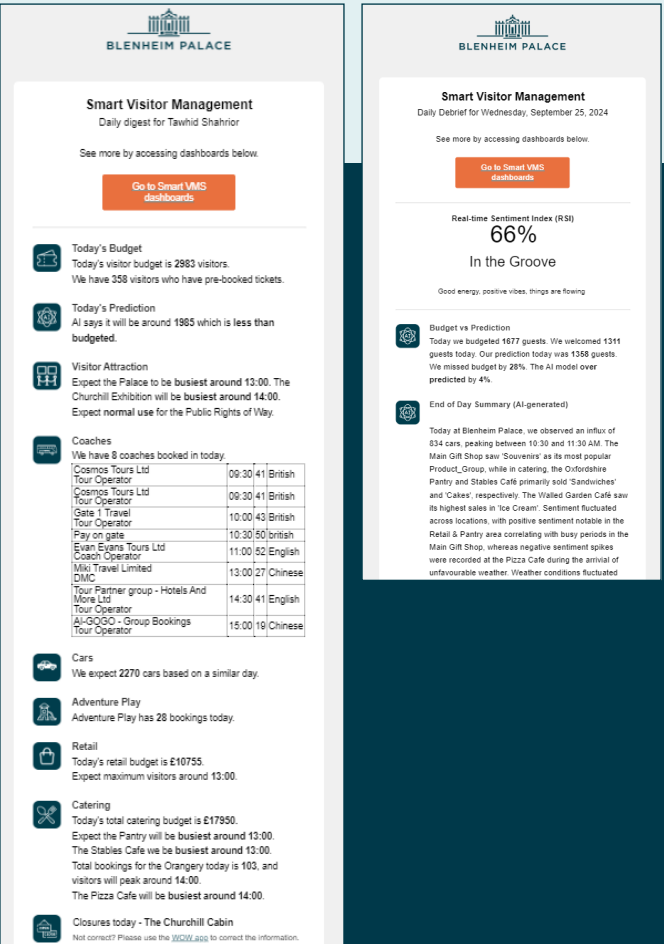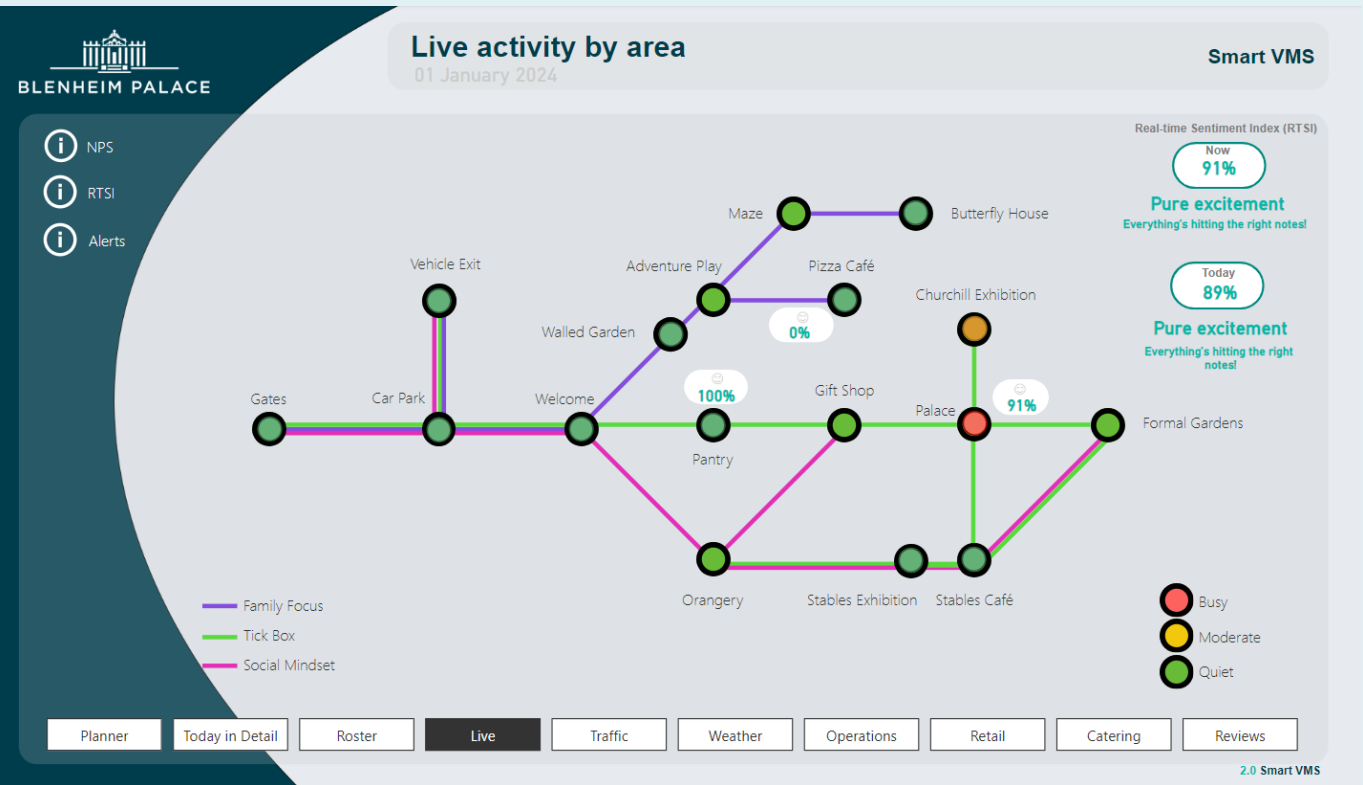
In the search for a more data-driven approach to staff planning, Blenheim has recently been working on a series of decision-making aids for palace managers. In each case, systems are driven by the general prediction algorithm (in terms of visitor numbers), but they also draw in data from the HR system.

Because each area of work across the palace is different - between, but also within areas (e.g. catering and visitor operations) - a range of different models have been developed.

This reflects the fact that different numbers of staff will be needed as demand rises and falls; but it also accounts for the way staff need organising into team configurations (people do different roles as part of an overall process). The models further recognise that variabilities in demand are also dependent on the day of the week and whether there is a school holiday, as well as on the weather or the season.

A 'tube map' display has been developed as part of this, and shows the flow of demand between different areas, reflecting people and staff hours.

Real-time Sentiment Index (RSI)

1. In the Blues- 0 to 20

Deep dissatisfaction, everything's out of tune

2. Off-Key - 21 to 40

Some missteps, things not quite clicking

3. Coasting Cool - 41 to 60

Smooth and steady, but no standout moments

4. In the Groove - 61 to 80

Good energy, positive vibes, things are flowing

5. Pure excitement- 81 to 100

Everything's hitting the right notes!

It's fair to say that Blenheim is at the start of the journey in embracing the new digital capabilities and embedding them in new working practices and decision-making processes. A 'benefits realisation' role has been created, to improve the dialogue between the development team and business users. This role will also help to capture and record the tangible differences the Smart VMS has made to the palace. But some clear returns can already be seen from the investment in the new technologies.

More accurate predictions of visitor numbers: "Predictions 80% more accurate than the budget."

Implementing a smart visitor management system has significantly enhanced Blenheim's operational efficiency by providing more accurate predictions of visitor numbers, which supports key planning decisions.

With these improved forecasts, Blenheim can optimise staff rostering to ensure that resources are allocated effectively, aligning staffing levels with expected demand. The system's real-time alerts enable proactive responses to potential issues before they escalate, ensuring a seamless visitor experience. Additionally, the Similar Day algorithm refines demand forecasts by identifying patterns from comparable days, allowing Blenheim to anticipate visitor flow accurately and prepare accordingly. This data-driven approach helps Blenheim deliver a more responsive and well-coordinated experience for their guests.

Better information to help visitor experience

The Smart VMS allows Blenheim to subtly guide visitors to enhance their experience. By analysing visitor flow and preferences, the system provides timely nudges through notifications, suggesting quieter areas and optimising routes.

Strategic decision-making

The Smart Visitor Management System has become an invaluable tool for strategic decision-making. By providing detailed insights into visitor behaviour and trends, it enables Blenheim to make informed decisions that align with both operational goals and visitor satisfaction. Accurate predictions of visitor numbers, for instance, support long-term planning around staffing, resource allocation, and infrastructure improvements. Real-time data also helps identify emerging patterns, allowing managers to adjust marketing strategies and tailor offerings based on visitor interests.

Evidence-based management

The Smart VMS supports evidence-based management by providing data-driven insights that inform every aspect of operations. With accurate, real-time data on visitor numbers, behaviour and preferences, Blenheim can make decisions grounded in concrete evidence rather than assumptions. By leveraging patterns and trends, Blenheim can fine-tune visitor experiences and respond proactively to emerging issues. This evidence-based approach not only enhances operational efficiency but also helps Blenheim to continuously refine and elevate the quality of their visitor offering.

Acknowledgements

The collaboration between Oxford Brookes and Blenheim Palace was made possible through the KTP funding from Innovate UK. We're also grateful to Matt Hogan, our KTP Adviser throughout the project.

The support of senior management at Blenheim has also been invaluable, underlining the strategic significance of the work. Thanks also go to the many members of staff that provided input and feedback into the development of activities and patiently engaged with early versions of the technologies as they emerged over the past few years.

Oxford Brookes has provided backing for our work and always encouraged our efforts to innovate and engage with the wider sector.

The work on the Smart VMS has involved a core team of Oxford Brookes and Blenheim staff. The work has been led at Blenheim by David Green, as head of innovation. The two AI developers on the project were Dr Yayoi Teramoto and Tawhid Shahrior. The team from Oxford Brookes comprised Dr Matthias Rolf, Dr Paul Jackson and Dr Diana Limburg.

As part of the collaboration, a number of Brookes developers and students have worked on side projects at the palace. These include Oli Adams, Methuselah Singh, Thomas Galea, Tom Blackburn, Filip Borowiak and Nikita Krasnytskyi.

Contact details for Blenheim and Brookes

Please contact Oxford Brookes via:

Dr Paul Jackson
Oxford Brookes Business School
Headington Campus
Oxford Brookes University
Oxford, OX3 0BP
E: pjackson@brookes.ac.uk

Please contact Blenheim Palace via:

Mr David Green
Estate Office
Blenheim Palace
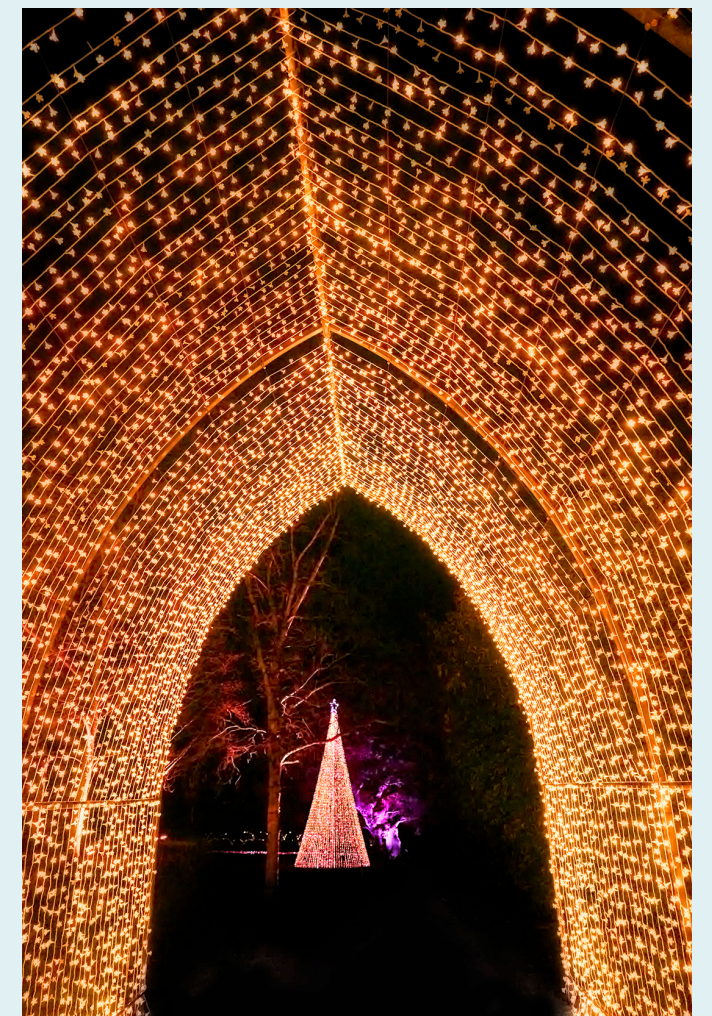Woodstock, OX20 1PP
E: DGreen@blenheimpalace.com

Ways to get involved in our work

If you're interested in hearing more about the projects at Blenheim, or related work at Oxford Brookes, feel free to use the contact information above.

During 2024 and 2025, the team is hoping to visit a range of visitor attractions, to explain the process of creating the Smart VMS and work through the challenges that might be involved locally to make progress on this agenda.

There may, of course, be related initiatives you know about that you think the partners should get involved with. Please say so.

Brookes, as a university, is doing a wide range of teaching and research in the areas related to the VMS, which you might also want to explore. Whatever your question or interest is, please get in touch.